

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 :

H04B 7/005

A1

(11) International Publication Number:

WO 00/18033

(43) International Publication Date:

30 March 2000 (30.03.00)

(21) International Application Number:

PCT/SE99/01607

(22) International Filing Date:

14 September 1999 (14.09.99)

(30) Priority Data:

09/156,695

18 September 1998 (18.09.98)

US

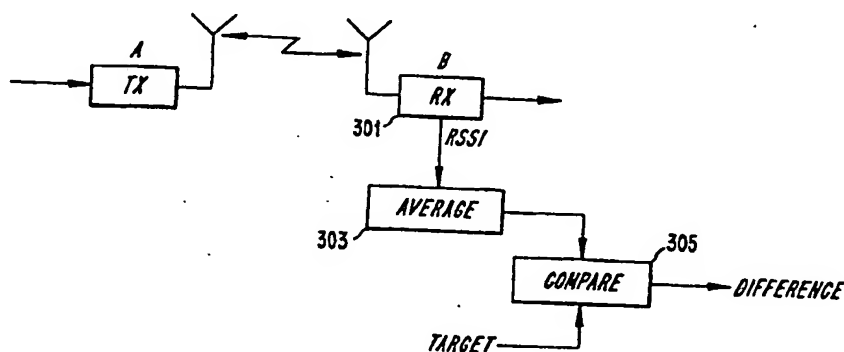
(71) Applicant: TELEFONAKTIEBOLAGET LM ERICSSON
(publ) [SE/SE]; S-126 25 Stockholm (SE).(72) Inventors: MATTISSON, Sven; Majorsvägen 1, S-237
32 Bjärred (SE). HAARTSEN, Jaap; Bruchterweg 81,
NL-7772 BG Hardenberg (NL).(74) Agent: ERICSSON MOBILE COMMUNICATIONS AB; IPR
Dept., S-221 83 Lund (SE).

(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published

*With international search report.**Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.*

(54) Title: AUTOMATIC POWER CONTROL IN UNCOORDINATED FREQUENCY-HOPPING RADIO SYSTEMS



(57) Abstract

Transmission power in a frequency-hopping radio system that transmits packets from a sending radio unit to a receiving radio unit, wherein each packet includes an address designating the receiving radio unit, is controlled by measuring received signal strength of packets whose addresses were successfully received in the receiving radio unit, regardless of whether other portions of the respective packets were successfully received. An average signal strength value is generated from the received signal strength measurements. The mathematical difference between the average signal strength value and a target value associated with the receiving radio unit is then determined and used as a basis for deciding whether to send a power control message from the receiving radio unit to the sending radio unit. In order to provide a hysteresis in the power control process, a power control message is sent from the receiving radio unit to the sending radio unit if the mathematical difference is greater than a first decision boundary, or if the mathematical difference is less than a second decision boundary. The power control message may itself include the mathematical difference which, when received by the sending radio unit, is used as a basis for determining a transmission power level adjustment amount. The target value, against which the average signal strength value is compared, may be based on the receiver sensitivity adjusted to account for implementation losses and other inaccuracies.

BEST AVAILABLE COPY

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakhstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Licchtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

AUTOMATIC POWER CONTROL IN UNCOORDINATED FREQUENCY-HOPPING RADIO SYSTEMS

BACKGROUND

The invention relates to radio systems that apply frequency hopping
5 (FH) spread spectrum techniques. More particularly, the invention relates to power control techniques for use in radio systems in which several, uncoordinated and non-synchronized FH systems cover the same area.

In the past few decades, progress in radio and Very Large Scale
Integration (VLSI) technology has fostered widespread use of radio communications in
10 consumer applications. Portable devices, such as mobile radios, can now be produced having acceptable cost, size and power consumption characteristics.

Although wireless technology is today focused mainly on voice
communications (e.g., with respect to handheld radios), this field will likely expand in
the near future to provide greater information flow to and from other types of nomadic
15 devices and fixed devices. More specifically, it is likely that further advances in technology will provide very inexpensive radio equipment that can be easily integrated into many devices. This will reduce the number of cables currently used. For example, radio communication can eliminate or reduce the number of cables used to connect master devices with their respective peripherals.

20 The aforementioned radio communications will require an unlicensed band with sufficient capacity to allow for high data rate transmissions. A suitable band is the Industrial, Scientific and Medical (ISM) band at 2.4 GHz, which is globally available. The band provides 83.5 MHz of radio spectrum.

To allow different radio networks to share the same radio medium
25 without coordination, signal spreading is usually applied. In fact, the FCC in the United States currently requires radio equipment operating in the 2.4 GHz band to apply some form of spreading when the transmit power exceeds about 0 dBm. Spreading can be either at the symbol level by applying direct-sequence spread spectrum or at the channel level by applying frequency hopping (FH) spread spectrum.

The latter is attractive for the radio applications mentioned above since it more readily allows the use of cost-effective radios.

The range of a radio link is generally determined by the transmit power of the sender in conjunction with the receiver sensitivity of the recipient, the receiver sensitivity being that received signal level for which acceptable reception is just possible. The receiver sensitivity is normally determined by the noise characteristics in the receiver which in turn depend on the bandwidth and allowable supply currents. Generally, the receiver sensitivity of a radio is fixed at the time of manufacturing. In contrast, the transmit (TX) power is usually a variable. Apart from hardware and power supply limitations, the maximum TX power is limited by government regulations. Even in an unlicensed band like the 2.4 GHz ISM band, maximum TX power is limited to 1 W. However, in the type of applications mentioned above, it is unnecessary to fix the TX power at its maximum. Rather, the TX power is regulated down such that the recipient receives a just sufficient amount of signal power for acceptable link quality. Reducing the TX power to the level just needed will reduce power consumption, thereby not only extending battery life, but also reducing interference. Reduction of interference is especially important if many uncoordinated radio networks share the same medium.

The TX power should always be controlled to an acceptable minimum in order to maintain acceptable link quality. In the type of applications mentioned above, the communicating radio units are peer units, and each seeks to reduce its TX power as much as possible. This results in a closed-loop power control algorithm, in which the recipient informs the sender to increase or decrease its TX power depending on the receive conditions. Such an automatic power control scheme has been described by G.H. Flammer, in U.S. Patent No. 5,465,398, issued Nov. 7, 1995 ("Automatic Power Level Control of a Packet Communication Link"). This patent describes a procedure in which the TX power of the sender is regulated based on Received Signal Strength Indication (RSSI) in the recipient. In accordance with the described conventional technique, power control is relative in that the lowest RSSI value of a successfully-received packet is used as a reference value. "Successful" in this context means that the entire packet, including the payload data, has been received without error. For those packets that are (successfully) received with a higher RSSI level, the difference

between the higher RSSI level and the reference value is determined and communicated to the sender, which can then reduce its TX power. Packets that are not successfully received are retransmitted at a higher TX power.

5 The problem with this scheme is that it does not distinguish between range and interference. The failure to successfully receive a packet can be attributed either to the signal level being too low, or to the interference level being too high. This is especially true in a situation in which many uncoordinated radio systems cover the same area: these systems will interfere with each other and packets will be lost due to collisions of different radio transmissions. Were an automatic power control
10 strategy such as that described by Flammer to be employed under these conditions, all radio units would increase their power, which would only worsen the situation because the coverage area and therefore the number of mutual interferers would increase. In fact, the systems may become unstable. In an unlicensed band like the ISM band where operation of the radio units is uncoordinated and the radio units operate
15 independently of each other, a power control strategy based on interference will result in an unfair domination of that system having the largest TX power.

An additional problem relates to the bursty interference conditions in FH systems: as the different systems hop uncoordinated through the spectrum, the interference only occurs if they happen, by chance, to use the same hop frequency at
20 the same time. Due to the hopping, the interference conditions change for every hop. If the system hops at the packet rate, adjusting the power based on the successful reception of a packet is not very stable.

SUMMARY

25 The foregoing and other objects are achieved in transmission power control methods and apparatuses for use in a frequency-hopping radio system that transmits packets from a sending radio unit to a receiving radio unit, wherein each packet includes an address designating the receiving radio unit. In accordance with one aspect of the invention, the received signal strength of packets whose addresses were successfully received in the receiving radio unit is measured, regardless of whether
30 other portions of the respective packets were successfully received; and an average signal strength value is generated from the received signal strength measurements. A

mathematical difference between the average signal strength value and a target value associated with the receiving radio unit is then determined, and used as a basis for deciding whether to send a power control message from the receiving radio unit to the sending radio unit.

5 In another aspect of the invention, using the mathematical difference as a basis for deciding whether to send a power control message from the receiving radio unit to the sending radio unit comprises sending a power control message from the receiving radio unit to the sending radio unit if the mathematical difference is greater than a first decision boundary or less than a second decision boundary.

10 In yet another aspect of the invention, the power control message may include the mathematical difference.

 In still another aspect of the invention, the power control message is received in the sending radio unit, which then adjusts its transmission power level unit by an amount based on the mathematical difference.

15 In yet another aspect of the invention, adjusting the transmission power level in the sending radio unit by an amount based on the mathematical difference includes determining whether the amount based on the mathematical difference would cause an adjusted transmission power level to exceed a predefined maximum transmission power level. If the amount based on the mathematical difference would
20 cause the adjusted transmission power level to exceed the predefined maximum transmission power level, then the transmission power level in the sending radio unit is adjusted to be no more than the predefined maximum transmission power level.

 In still another aspect of the invention, when the sending radio unit is at the predefined maximum TX power level, a control message is sent from the sending
25 radio unit to the receiving radio unit informing that a maximum transmission power level has been reached.

 In yet another aspect of the invention, the receiving radio unit responds to the control message from the sending radio unit informing that a maximum transmission power level has been reached, by sending no further power control
30 messages to the sending radio unit that instruct the sending radio unit to further increase its transmission power level.

In still another aspect of the invention, adjusting the transmission power level in the sending radio unit by an amount based on the mathematical difference includes determining whether the amount based on the mathematical difference would cause an adjusted transmission power level to fall below a predefined minimum transmission power level. If the amount based on the mathematical difference would cause the adjusted transmission power level to fall below the predefined minimum transmission power level, then the transmission power level in the sending radio unit is adjusted to be no less than the predefined minimum transmission power level.

In yet another aspect of the invention, when the sending radio unit is at the predefined minimum TX power level, a control message is sent from the sending radio unit to the receiving radio unit informing that the minimum transmission power level has been reached.

In still another aspect of the invention, the receiving radio unit responds to the control message from the sending radio unit informing that a minimum transmission power level has been reached, by sending no further power control messages to the sending radio unit that instruct the sending radio unit to further decrease its transmission power level.

In yet another aspect of the invention, the target value associated with the receiving radio unit is based on the receiver sensitivity alone, or adjusted to account for implementation losses and other inaccuracies.

In still another aspect of the invention, generating the average signal strength value from the received signal strength measurements may include averaging signal strength values from the received signal strength measurements over a period of time extending over at least two frequency hops.

In yet another aspect of the invention, the power control message is transmitted on a control channel established between the receiving radio unit and the sending radio unit. Alternatively, it may be included in a return packet that is transmitted from the receiving radio unit to the sending radio unit.

In still another aspect of the invention, a highest permissible transmit power level is always used to send the power control message from the receiving radio unit to the sending radio unit. Alternatively, a first transmit power level is initially used to send the power control message from the receiving radio unit to the sending

radio unit. The power control message transmit power level is then gradually increased from the first transmit power level to successively higher levels until a reception signal strength level at the receiving radio unit has reached a predefined acceptable level.

BRIEF DESCRIPTION OF THE DRAWINGS

5 The objects and advantages of the invention will be understood by reading the following detailed description in conjunction with the drawings in which:

FIG. 1 depicts an interference scenario involving four radio units employing high transmission power levels;

10 FIG. 2 depicts an interference scenario involving four radio units employing low transmission power levels;

FIG. 3 is a block diagram depicting circuits at sender and recipient radio units for maintaining a power control loop in accordance with one aspect of the invention;

15 FIG. 4 is a flow diagram of a power control procedure performed at the recipient radio unit in accordance with one aspect of the invention; and

FIG. 5 is a flow diagram of power control procedure performed at the sender radio unit in accordance with one aspect of the invention.

DETAILED DESCRIPTION

20 The various features of the invention will now be described with respect to the figures, in which like parts are identified with the same reference characters.

25 FIG. 1 depicts two independent frequency hopping (FH) radio links 101, 103 operating in the vicinity of one another. Exemplary systems that utilizes such links are described in U.S. Patent Application No. 08/932,911, filed on September 17, 1997 (Haartsen); and U.S. Patent Application No. 08/932,244, filed on September 17, 1997 (Haartsen), the entire disclosures of which are hereby incorporated by reference herein in their entireties. The coverage range of each radio unit is indicated by a dashed circle. Units A and B communicate according to one FH scheme, while units C and D communicate according to another FH scheme. The two radio links 101, 103 are uncoordinated and occasionally make use of the same hop channel. Depending on the
30 relative distances between the various units A, B, C, D, one or both transmissions may

fail in that case. In the case illustrated in FIG. 1, the coverage areas are such that collisions will indeed occur. Units C and D are in the coverage range of units A and B, and vice versa; A and B will therefore interfere with C and D and vice versa.

FIG. 2 illustrates a case in which the TX powers of the radio units have been reduced, resulting in the smaller coverage areas depicted by the dotted lines in the figure. In this case, the signal strengths of the two systems are insufficient to disturb each other's intended received signals, and collisions will not occur even if the two links use the same hop channel simultaneously. This concept is generally used in cellular systems where channels are reused at geographic locations spaced sufficiently apart so that the mutual interference is too weak to disturb the intended signals.

It is clear from FIGS. 1 and 2 that the TX power should always be set as low as possible since this will increase overall capacity (reuse gain). In addition, it will reduce power consumption and thus extend battery life. However, the strategy for determining the power level control should not be based on the interference level experienced, because such a strategy can result in both transceiver pairs increasing their power. When this happens, interference is not reduced, and power consumption is increased.

In accordance with one aspect of the invention, power control is based on the absolute signal level received at each recipient. The TX power of the sending unit is adjusted to a level such that the received signal level is sufficiently large enough to overcome the noise generated in the receiver (receiver sensitivity) plus some margin.

FIG. 3 is a block diagram depicting circuits at sender and recipient radio units for maintaining a power control loop in accordance with one aspect of the invention. A closed-loop power control strategy is used, in which, in one respect, unit A tells unit B what TX power to use based on signal strength measurements taken in unit A; and conversely, unit B tells unit A what TX power to use based on signal strength measurements taken in unit B. In order to facilitate an understanding of the invention, FIG. 3 depicts only those components involved in the procedure for controlling unit A's TX power. It will be readily understood that for controlling unit B's TX power, the same components and strategies would be employed, but with the roles of unit A and unit B being reversed.

Looking now at FIG. 3, unit B includes an RSSI measurement unit 301 that generates an RSSI value based on packets received from unit A. Each transmitted packet includes an address portion (e.g., in a header portion of the packet) that designates the intended recipient which, in this example, is unit B. Preferably, the only packets for which an RSSI measurement is made are those packets whose addresses are successfully received, regardless of whether other portions of the respective packets are successfully received. This is done in order to avoid having unit B regulate the power of unit A using packets erroneously received from a third unit (e.g., a nearby unit C). To facilitate a determination of whether a packet's address has been correctly received, forward error correction codes, such as header redundancy checks (HECs, which are the same as cyclic redundancy checks, or CRCs) may be (and typically are) added to the packet.

By only requiring that the address portion of the packet be successfully received, and not requiring that any other portion of the packet be successfully received, this aspect of the invention achieves an advantage in those situations in which the address, but not the packet payload (e.g., data) has been successfully received. (This can easily happen since packet headers are typically shorter than the payload portion, and include more forward error correction coding.) The advantage arises because by knowing at least that the packet was intended to be received by a particular receiving radio unit, that unit can still make an RSSI measurement on the packet, thereby enabling the power control mechanism to continue functioning (possibly increasing the transmit power level so that subsequent packet payloads will be received with fewer errors). By contrast, conventional techniques that make measurements only on those packets that were successfully received in their entirety, can break down when erosion of the transmission link between the sending and receiving radio units causes no packets to be successfully received. In this case, no signal strength measurements are made at all, so no power controls are generated and no closed-loop power control can be sustained in conventional systems.

Returning now to a discussion of FIG. 3, the packets are assumed to be sent on different hop channels, as is customary in FH radio systems. Different systems can have different relationships between the amount of time required to transmit one packet and the frequency hop dwell time (i.e., the amount of time that the FH radio

systems spends communicating over any one of the various frequencies in the hop sequence). For example, the hop dwell time can be just long enough to permit the transmission of just one packet. Alternatively, the hop dwell time may be long enough to permit the transmission of two or more packets. In a preferred embodiment, unit B includes averaging circuitry 303 that accumulates the RSSI of packets received over many hops on different frequencies (e.g., over at least two, and in some embodiments all of the hops in a hop sequence), and determines an average RSSI. The averaging circuitry 303 may alternatively be hardwired components, programmed processing components, or a combination of both.

10 In another aspect of the invention, unit B further includes a comparator 305 that compares the average value determined in unit B with a target value, and determines therefrom a mathematical difference. In alternative embodiments, the mathematical difference can be represented by signals of any resolution, from 1 bit and higher, depending on the design of the overall system, and can represent positive as well as negative values. The target value used in the comparison can, for example, be the receiver sensitivity of unit B. In some embodiments, it may be advantageous to add a margin amount to the receiver sensitivity in order to determine the target value. Note that the receiver sensitivity may vary from unit to unit. More advanced units may have a lower receiver sensitivity and therefore require less TX power for the same range. In alternative embodiments, the target value can be based on parameters that are unrelated to receiver sensitivity.

The mathematical difference between the average RSSI value and the target value is then sent back to the sender (unit A in this example). This can, for example, be accomplished via a special control channel between unit A and B.

25 Alternatively, the mathematical difference value may be piggy backed (i.e., included) in the return packet sent from unit B to unit A. If the mathematical difference is positive, the measured RSSI value is larger than that which is required for the current distance between units A and B. In this case, unit A may reduce its TX power. If the mathematical difference is negative, then unit A may increase its TX power. Note that unit A only adjusts its current TX power level by an amount based on the received mathematical difference value. The particular relationship between the adjustment amount and the mathematical difference value will be system dependent.

Consequently, a full discussion of how to determine the adjustment amount based on the received mathematical difference value is beyond the scope of this disclosure. In general, unit B will only request a change in TX power when the mathematical difference has exceeded a certain margin. In this way a hysteresis results that prevents unit B from requesting small up and down steps continuously. Such a situation would result in a rather large overhead if explicit power messages are used.

Flow diagrams of the power control procedures performed at the recipient and sender are respectively shown in FIGS. 4 and 5. Looking first at FIG. 4, the RSSI of those packets whose addresses were successfully received is measured (step 401). These RSSI values are then averaged over a period of time that preferably extends over a large number of hop frequencies (step 403). The average RSSI value is then compared with a target value (e.g., by subtracting one from the other) in order to obtain a mathematical difference value (step 405). In some embodiments, the mathematical difference value may, at this point, be used directly to determine whether an adjustment in TX power should be made (i.e., based on whether the mathematical difference is equal to zero).

However, in preferred embodiments, a hysteresis is created by utilizing the decision boundaries Δa and Δb in a decision step (step 407). Specifically, if the mathematical difference value is alternatively greater than the boundary Δa or less than the boundary Δb , then a power message including the mathematical difference value is sent to the sending unit (step 409). However, if neither of these test conditions is true, then no power message is transmitted. In either case, the entire process begins again at step 401 with the measurement of the RSSI for newly successfully received packets.

Looking now at FIG. 5, step 501 represents conventional processing that is performed by a radio unit. Such processing, of course, depends on the nature of the radio unit (e.g., whether it is wireless processing equipment, or some other type of equipment), and a discussion of this processing is outside the scope of this disclosure.

At some point, a determination is made as to whether a new power message has been received (step 503). If not, processing resumes at step 501.

However, if a new power message has been received, then the current TX level is adjusted by an amount determined by the contents of the new power message (step 507). In some embodiments, TX level cannot be adjusted above

predefined maximum and/or below predefined minimum levels. In such cases, the adjustment step 507 includes a test to see if the intended adjustment would cause the adjusted TX level to either exceed the predefined maximum level, or fall below the predefined minimum level. In such cases, no adjustment beyond these limits is made.

- 5 In such cases, it is preferable (although not required in all embodiments) for the sending radio unit to send a control message to the receiving radio unit informing that the maximum/minimum TX power level has been achieved. In response, the receiving radio unit should send no further power control messages that attempt to cause the sending radio unit to adjust the TX power level beyond the predefined limits.
- 10 Specifically, when the receiving radio unit learns that the sending radio unit is at the predefined maximum TX power level, it will send no further control messages that attempt to further increase the TX power level beyond the predefined maximum TX power level. Similarly, when the receiving radio unit learns that the sending radio unit is at the predefined minimum TX power level, it will send no further control messages
- 15 that attempt to further decrease the TX power level to a level that is lower than the predefined minimum TX power level.

Following the adjustment step 507, processing proceeds as usual (step 501).

- 20 The above-described procedure establishes a closed loop between sender and recipient for controlling the TX power of the sender. This procedure fails as soon as the loop is "broken". For example, if the link attenuation were suddenly to increase due to an object between sender and recipient, the recipient would have no ability to instruct the sender to increase its TX power. To account for this situation, two alternative solutions may be applied. In one embodiment, the control packet carrying
- 25 the power control message is always sent at the highest allowable TX power. In an alternative embodiment, the power of the control packet carrying the power control message starts at a first power level. If the reception level at the receiving radio unit is not increased, this is presumably due to the sending unit not receiving the power control message. Therefore, starting at the first power level, the power of the control
- 30 packet carrying the power control message is gradually increased until the reception level at the receiving radio unit has reached a satisfying level again. Note that this

procedure is applied only for those packets that include power control messages. For all other messages, the other side has to request for the increase of TX power.

If a unit has several connections to different units (e.g., a master unit in communication with a number of slave units), it should support a power control loop to each unit independently. That is, the power of the packet transmission will depend on the distance and target reception value of each individual recipient. If a unit wants to send broadcast packets to all linked units, the broadcast message should either be sent at the maximum power level, or alternatively at the highest one of all of the various power levels required by the receiving units (i.e., the power level required by that unit having the weakest link between itself and the broadcasting unit).

The invention has been described with reference to a particular embodiment. However, it will be readily apparent to those skilled in the art that it is possible to embody the invention in specific forms other than those of the preferred embodiment described above. This may be done without departing from the spirit of the invention. The preferred embodiment is merely illustrative and should not be considered restrictive in any way. The scope of the invention is given by the appended claims, rather than the preceding description, and all variations and equivalents which fall within the range of the claims are intended to be embraced therein.

WHAT IS CLAIMED IS:

1. A method of controlling transmission power in a frequency-hopping radio system that transmits packets from a sending radio unit to a receiving radio unit, wherein each packet includes an address designating the receiving radio unit, the
5 method comprising the steps of:

measuring received signal strength of packets whose addresses were successfully received in the receiving radio unit, regardless of whether other portions of the respective packets were successfully received;

- 10 generating an average signal strength value from the received signal strength measurements;

determining a mathematical difference between the average signal strength value and a target value associated with the receiving radio unit; and

using the mathematical difference as a basis for deciding whether to send a power control message from the receiving radio unit to the sending radio unit.

- 15 2. The method of claim 1, wherein the step of using the mathematical difference as a basis for deciding whether to send a power control message from the receiving radio unit to the sending radio unit comprises the steps of:

20 sending a power control message from the receiving radio unit to the sending radio unit if the mathematical difference is greater than a first decision boundary; and

sending the power control message from the receiving radio unit to the sending radio unit if the mathematical difference is less than a second decision boundary.

- 25 3. The method of claim 1, wherein the power control message includes the mathematical difference.

4. The method of claim 3, further comprising the steps of:
receiving the power control message in the sending radio unit; and
adjusting a transmission power level in the sending radio unit by an amount based on the mathematical difference.

5. The method of claim 4, wherein the step of adjusting the transmission power level in the sending radio unit by an amount based on the mathematical difference comprises:

determining whether the amount based on the mathematical difference would cause an adjusted transmission power level to exceed a predefined maximum transmission power level;

if the amount based on the mathematical difference would cause the adjusted transmission power level to exceed the predefined maximum transmission power level, then adjusting the transmission power level in the sending radio unit to be no more than the predefined maximum transmission power level.

6. The method of claim 5, further comprising the step of:
sending a control message from the sending radio unit to the receiving radio unit informing that a maximum transmission power level has been reached.

7. The method of claim 6, further comprising the step of:
in the receiving radio unit, in response to the control message from the sending radio unit informing that a maximum transmission power level has been reached, sending no further power control messages to the sending radio unit that instruct the sending radio unit to further increase its transmission power level.

8. The method of claim 4; wherein the step of adjusting the transmission power level in the sending radio unit by an amount based on the mathematical difference comprises:

determining whether the amount based on the mathematical difference would cause an adjusted transmission power level to fall below a predefined minimum transmission power level;

if the amount based on the mathematical difference would cause the adjusted transmission power level to fall below the predefined minimum transmission power level, then adjusting the transmission power level in the sending radio unit to be no less than the predefined minimum transmission power level.

9. The method of claim 8, further comprising the step of:
sending a control message from the sending radio unit to the receiving
radio unit informing that a minimum transmission power level has been reached.
10. The method of claim 9, further comprising the step of:
5 in the receiving radio unit, in response to the control message from the
sending radio unit informing that a minimum transmission power level has been
reached, sending no further power control messages to the sending radio unit that
instruct the sending radio unit to further decrease its transmission power level.
11. The method of claim 1, wherein the target value associated with the
10 receiving radio unit is based on the receiver sensitivity.
12. The method of claim 1, wherein the target value associated with the
receiving radio unit is based on the receiver sensitivity adjusted to account for
implementation losses and other inaccuracies.
13. The method of claim 1, wherein the step of generating the average signal
15 strength value from the received signal strength measurements comprises the step of:
averaging signal strength values from the received signal strength
measurements over a period of time extending over at least two frequency hops.
14. The method of claim 1, further comprising the step of:
when it is decided to send the power control message from the receiving
20 radio unit to the sending radio unit, sending the power control message on a control
channel established between the receiving radio unit and the sending radio unit.
15. The method of claim 1, further comprising the step of:
when it is decided to send the power control message from the receiving
radio unit to the sending radio unit, including the power control message in a return
25 packet that is transmitted from the receiving radio unit to the sending radio unit.

16. The method of claim 1, further comprising the step of:
when it is decided to send the power control message from the receiving
radio unit to the sending radio unit, always using a highest permissible transmit power
level to send the power control message from the receiving radio unit to the sending
5 radio unit.

17. The method of claim 1, further comprising the step of:
when it is decided to send the power control message from the receiving
radio unit to the sending radio unit, initially using a first transmit power level to send
the power control message from the receiving radio unit to the sending radio unit, and
10 then gradually increasing the power control message transmit power level from the first
transmit power level to successively higher levels until a reception signal strength level
at the receiving radio unit has reached a predefined acceptable level.

18. An apparatus for controlling transmission power in a frequency-hopping
radio system that transmits packets from a sending radio unit to a receiving radio unit,
15 wherein each packet includes an address designating the receiving radio unit, the
apparatus comprising:

means for measuring received signal strength of packets whose addresses
were successfully received in the receiving radio unit, regardless of whether other
portions of the respective packets were successfully received;

20 means for generating an average signal strength value from the received
signal strength measurements;

means for determining a mathematical difference between the average
signal strength value and a target value associated with the receiving radio unit; and

25 means for using the mathematical difference as a basis for deciding
whether to send a power control message from the receiving radio unit to the sending
radio unit.

19. The apparatus of claim 18, wherein the means for using the
mathematical difference as a basis for deciding whether to send a power control
message from the receiving radio unit to the sending radio unit comprises:

means for sending a power control message from the receiving radio unit to the sending radio unit if the mathematical difference is greater than a first decision boundary; and

5 means for sending the power control message from the receiving radio unit to the sending radio unit if the mathematical difference is less than a second decision boundary.

20. The apparatus of claim 18, wherein the power control message includes the mathematical difference.

10 21. The apparatus of claim 20, further comprising:
means for receiving the power control message in the sending radio unit;
and

means for adjusting a transmission power level in the sending radio unit by an amount based on the mathematical difference.

15 22. The apparatus of claim 21, wherein the means for adjusting the transmission power level in the sending radio unit by an amount based on the mathematical difference comprises:

means for determining whether the amount based on the mathematical difference would cause an adjusted transmission power level to exceed a predefined maximum transmission power level;

20 means, response to a determination that the amount based on the mathematical difference would cause the adjusted transmission power level to exceed the predefined maximum transmission power level, for adjusting the transmission power level in the sending radio unit to be no more than the predefined maximum transmission power level.

25 23. The apparatus of claim 22, further comprising:
means for sending a control message from the sending radio unit to the receiving radio unit informing that a maximum transmission power level has been reached.

24. The apparatus of claim 23, further comprising:

in the receiving radio unit, means, responsive to the control message from the sending radio unit informing that a maximum transmission power level has been reached, for sending no further power control messages to the sending radio unit
5 that instruct the sending radio unit to further increase its transmission power level.

25. The apparatus of claim 21, wherein the means for adjusting the transmission power level in the sending radio unit by an amount based on the mathematical difference comprises:

means for determining whether the amount based on the mathematical
10 difference would cause an adjusted transmission power level to fall below a predefined minimum transmission power level;

means, responsive to a determination that the amount based on the mathematical difference would cause the adjusted transmission power level to fall below the predefined minimum transmission power level, for adjusting the transmission
15 power level in the sending radio unit to be no less than the predefined minimum transmission power level.

26. The apparatus of claim 25, further comprising:

means for sending a control message from the sending radio unit to the receiving radio unit informing that a minimum transmission power level has been
20 reached.

27. The apparatus of claim 26, further comprising the step of:

in the receiving radio unit, means, responsive to the control message from the sending radio unit informing that a minimum transmission power level has been reached, for sending no further power control messages to the sending radio unit
25 that instruct the sending radio unit to further decrease its transmission power level.

28. The apparatus of claim 18, wherein the target value associated with the receiving radio unit is based on the receiver sensitivity.

29. The apparatus of claim 18, wherein the target value associated with the receiving radio unit is based on the receiver sensitivity adjusted to account for implementation losses and other inaccuracies.

30. The apparatus of claim 18, wherein the means for generating the average
5 signal strength value from the received signal strength measurements comprises:
means for averaging signal strength values from the received signal strength measurements over a period of time extending over at least two frequency hops.

31. The apparatus of claim 18, further comprising:
10 means, responsive to a decision to send the power control message from the receiving radio unit to the sending radio unit, for sending the power control message on a control channel established between the receiving radio unit and the sending radio unit.

32. The apparatus of claim 18, further comprising:
15 means, responsive to a decision to send the power control message from the receiving radio unit to the sending radio unit, for including the power control message in a return packet that is transmitted from the receiving radio unit to the sending radio unit.

33. The apparatus of claim 18, further comprising:
20 means, responsive to a decision to send the power control message from the receiving radio unit to the sending radio unit, for always using a highest permissible transmit power level to send the power control message from the receiving radio unit to the sending radio unit.

34. The apparatus of claim 18, further comprising:
25 means, responsive to a decision to send the power control message from the receiving radio unit to the sending radio unit, for initially using a first transmit power level to send the power control message from the receiving radio unit to the

sending radio unit, and then gradually increasing the power control message transmit power level from the first transmit power level to successively higher levels until a reception signal strength level at the receiving radio unit has reached a predefined acceptable level.

FIG. 1

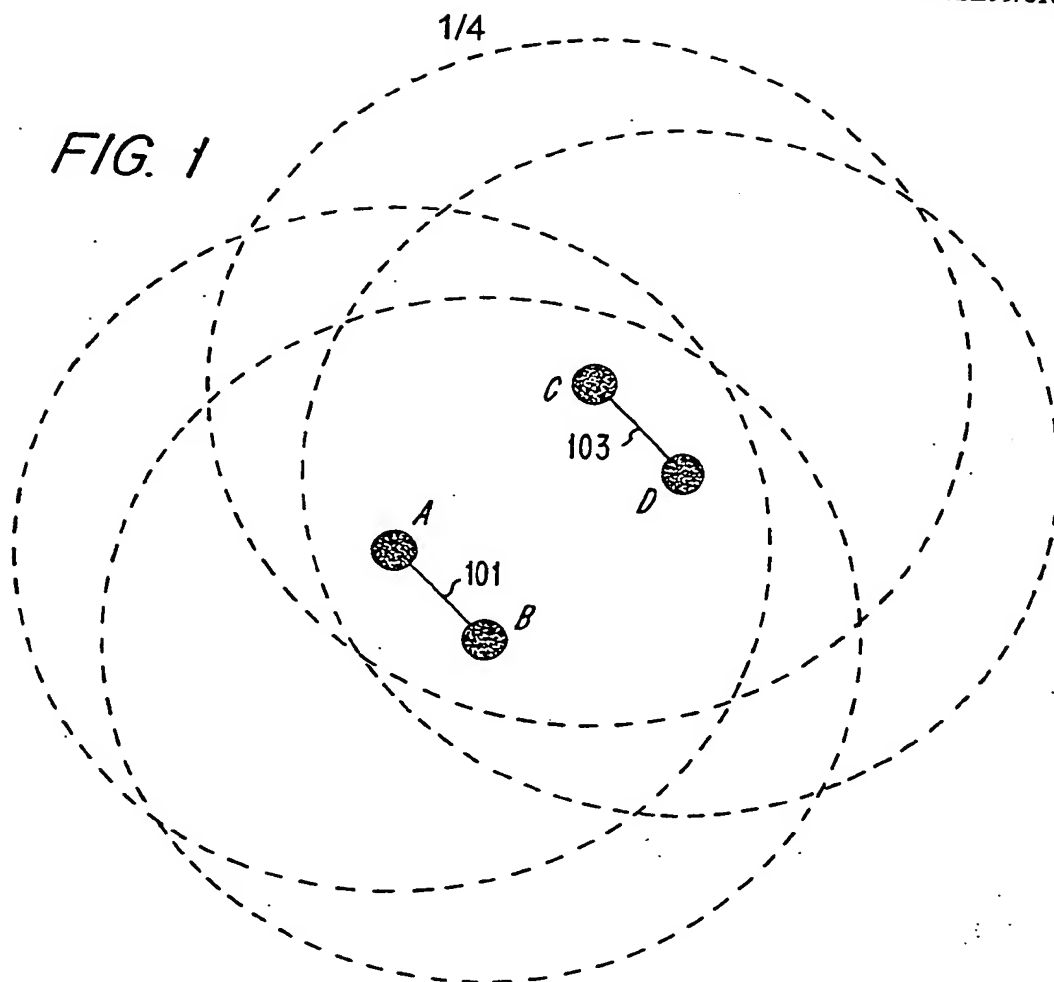


FIG. 2

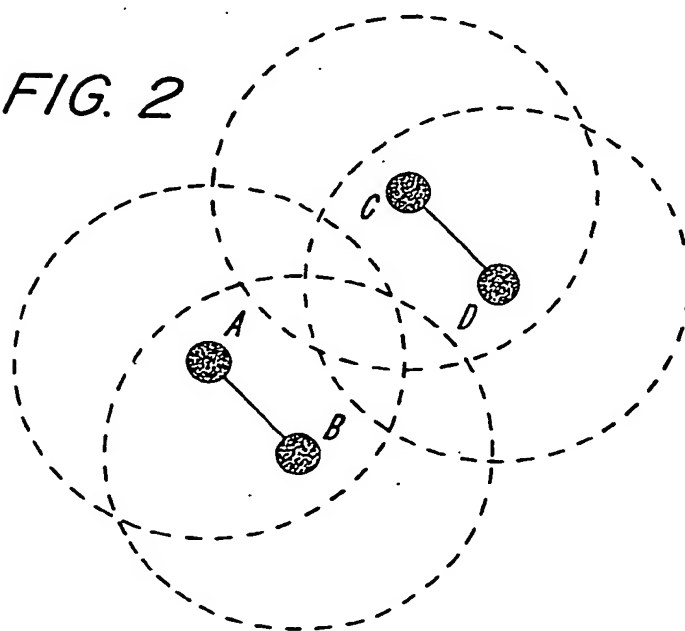


FIG. 3

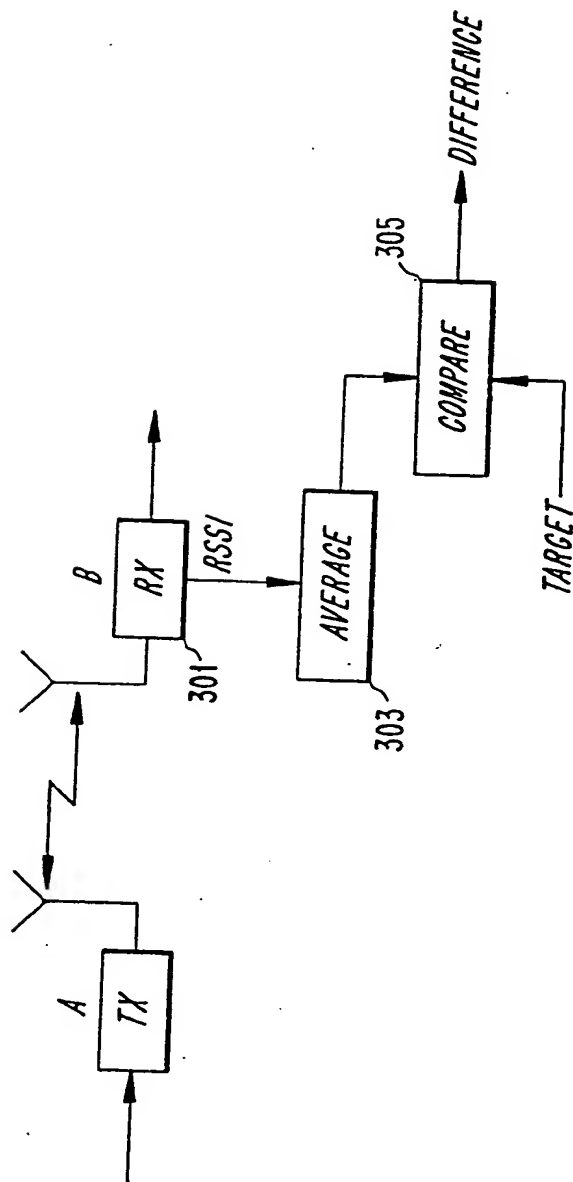


FIG. 4

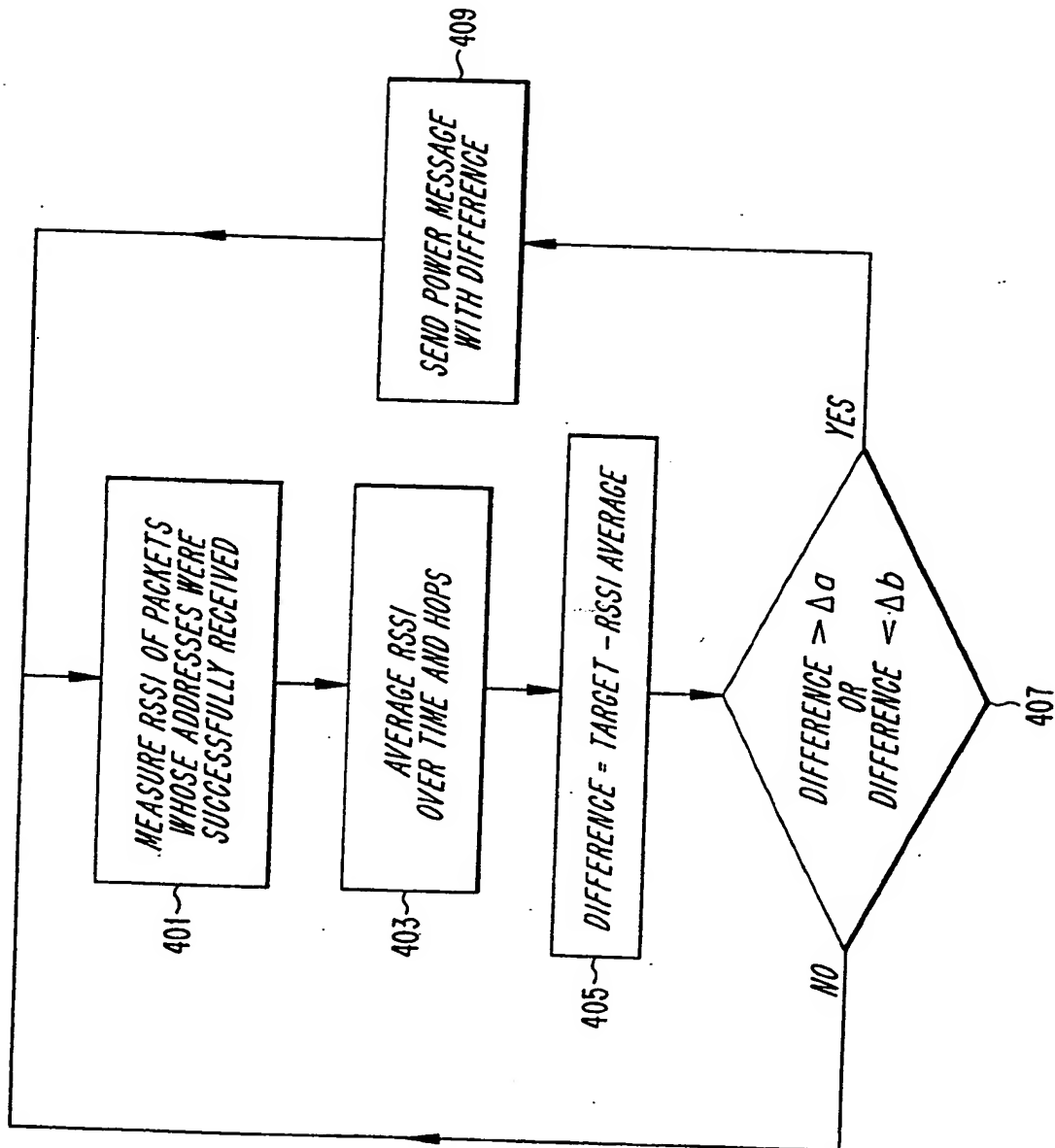
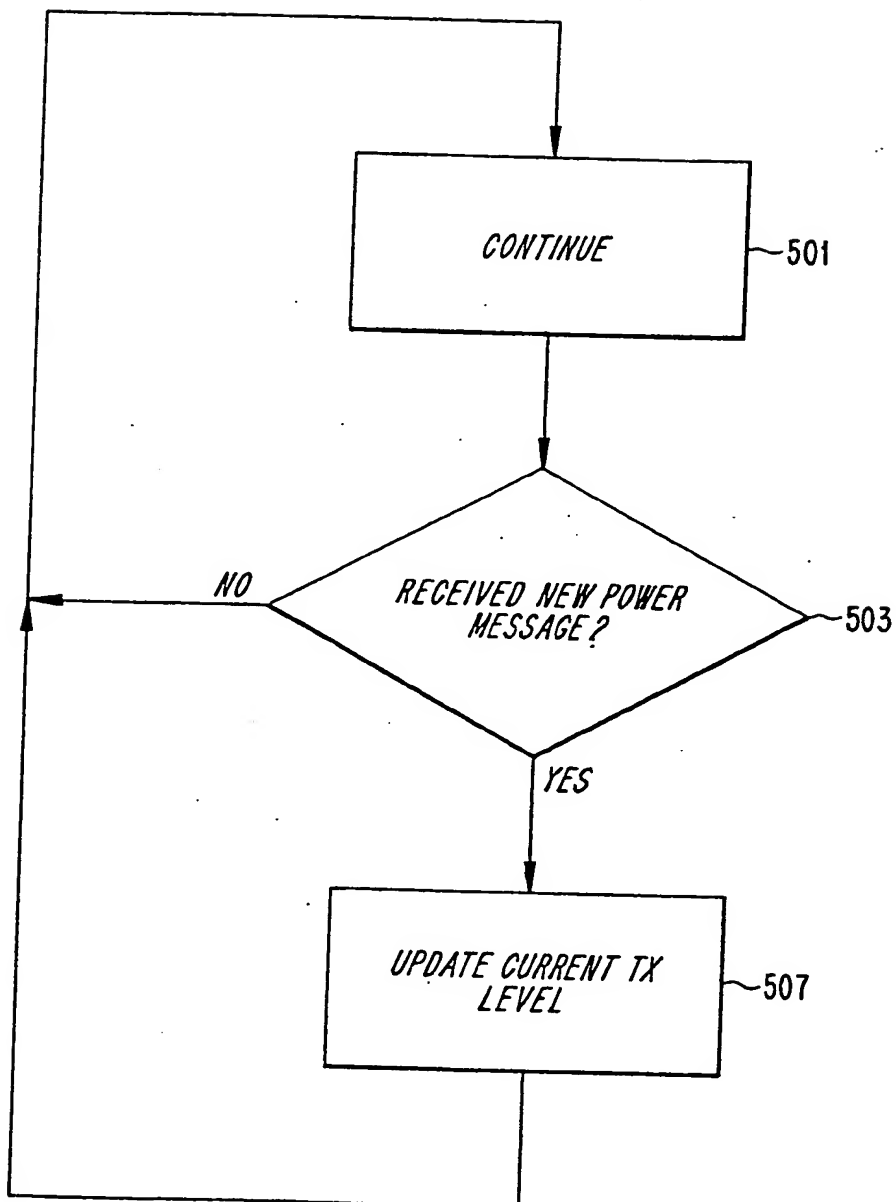


FIG. 5



INTERNATIONAL SEARCH REPORT

International Application No

PCT/SE 99/01607

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04B7/005

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H04B H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 465 398 A (FLAMMER GEORGE H) 7 November 1995 (1995-11-07) cited in the application figure 4 column 4, line 38 -column 5, line 5	1-34
A	US 5 574 979 A (WEST GUY J) 12 November 1996 (1996-11-12) figures 14,35,36 column 30, line 37 - line 46 column 54, line 1 -column 55, line 49	1-34
A	EP 0 548 939 A (NIPPON ELECTRIC CO) 30 June 1993 (1993-06-30) figure 2 column 7, line 7 - line 39	1-34
	--- -/-	

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search

2 February 2000

Date of mailing of the international search report

09/02/2000

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Eraso Helguera, J

INTERNATIONAL SEARCH REPORT

International Application No
PCT/SE 99/01607

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 462 952 A (ERICSSON TELEFON AB L M) 27 December 1991 (1991-12-27) figure 4 column 6, line 6 -column 11, line 7 -----	1-34
A	US 5 579 373 A (JANG BU-KWAN) 26 November 1996 (1996-11-26) figures 7,8 column 8, line 37 -column 9, line 11 -----	1-34

INTERNATIONAL SEARCH REPORT

information on patent family members

International Application No

PCT/SE 99/01607

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 5465398	A	07-11-1995	AU 7962694 A CA 2173250 A CN 1132578 A EP 0722635 A WO 9510142 A	01-05-1995 13-04-1995 02-10-1996 24-07-1996 13-04-1995
US 5574979	A	12-11-1996	NONE	
EP 0548939	A	30-06-1993	JP 2823034 B JP 5244056 A US 5386589 A	11-11-1998 21-09-1993 31-01-1995
EP 0462952	A	27-12-1991	SE 467332 B AT 121242 T AU 635429 B AU 7917391 A CA 2045211 A CN 1057557 A, B DE 69108793 D DE 69108793 T DK 462952 T ES 2073728 T HK 108795 A JP 4233334 A KR 9606142 B NZ 238269 A SE 9002228 A US 5241690 A	29-06-1992 15-04-1995 18-03-1993 02-01-1992 22-12-1991 01-01-1992 18-05-1995 24-08-1995 14-08-1995 16-08-1995 14-07-1995 21-08-1992 09-05-1996 26-10-1993 22-12-1991 31-08-1993
US 5579373	A	26-11-1996	KR 9600147 B	03-01-1996

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 :

H04L 1/12

A1

(11) International Publication Number:

WO 99/12304

(43) International Publication Date:

11 March 1999 (11.03.99)

(21) International Application Number: PCT/SE98/01538

(22) International Filing Date: 28 August 1998 (28.08.98)

(30) Priority Data:

08/921,321

29 August 1997 (29.08.97)

US

(71) Applicant: TELEFONAKTIEBOLAGET LM ERICSSON
(publ) [SE/SE]; S-126 25 Stockholm (SE).(72) Inventors: THIELECKE, Jörn; Rhönstrasse 24, D-91056
Erlangen (DE). OLOFSSON, Håkan; Ringvägen 50, S-118
67 Stockholm (SE).(74) Agent: ERICSSON RADIO SYSTEMS AB; Common Patent
Dept., S-164 80 Stockholm (SE).

(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, HR, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

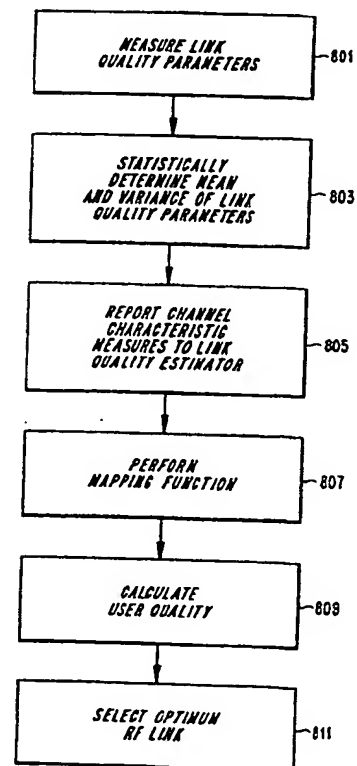
Published

With international search report.

(54) Title: A METHOD FOR SELECTING A COMBINATION OF MODULATION AND CHANNEL CODING SCHEMES IN A DIGITAL COMMUNICATION SYSTEM

(57) Abstract

A communication system that supports multiple modulation and channel coding schemes selects an optimum RF link by measuring link quality parameters, such as C/I ratio. All of the available RF links are characterized based on the measured link quality parameters by calculating mean values and variances of the parameters. Based on the characterization of the RF link, user quality values, such as user data throughput and speech quality values, are estimated. The communication system selects the RF link that provides the best user quality value.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakhstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

A METHOD FOR SELECTING A COMBINATION OF MODULATION AND
CHANNEL CODING SCHEMES IN A DIGITAL COMMUNICATION SYSTEM

BACKGROUND

5 This invention generally relates to the field of
communication systems and, more particularly, to digital
communication systems that supports multiple modulation and
channel coding schemes.

 In wireless digital communication systems,
10 standardized air interfaces specify most of system
parameters, including modulation scheme, channel coding
scheme, burst format, communication protocol, symbol rate,
etc. For example, European Telecommunication Standard
Institute (ETSI) has specified a Global System for Mobile
15 Communication (GSM) standard that uses time division
multiple access (TDMA) to communicate control, voice and
data information over radio frequency (RF) physical channels
or links using Gaussian Minimum Shift Keying (GMSK)
modulation scheme at a symbol rate of 271 kbps. In the
20 U.S., Telecommunication Industry Association (TIA) has
published a number of Interim Standards, such as IS-54 and
IS-136, that define various versions of digital advanced
mobile phone service (D-AMPS), a TDMA system that uses a
Differential QPSK (DQPSK) modulation scheme for
25 communicating data over RF links.

 Digital communication systems use a variety of
linear and non-linear modulation schemes to communicate
voice or data information in bursts. These modulation
schemes include, GMSK, Quadrature Phase Shift Keying (QPSK),
30 Quadrature Amplitude Modulation (QAM), etc. GMSK modulation

scheme is a non-linear low level modulation (LLM) scheme with a symbol rate that supports a specified user bit rate. In order to increase user bit rate, high-level modulation (HLM) schemes can be used. Linear modulation schemes, such as QAM scheme, may have different level of modulation. For example, 16QAM scheme is used to represent the sixteen variations of 4 bits of data. On the other hand, a QPSK modulation scheme is used to represent the four variations of 2 bits of data.

In addition to various modulation schemes, digital communication systems can support various channel coding schemes, which are used to increase communication reliability. For example, General Packet Radio Service (GPRS), which is a GSM extension for providing packet data service, supports four channel coding schemes. A Convolutional Half-Rate Code scheme, CS1 coding scheme, which is the "mother" channel coding scheme of GPRS. The CS1 scheme is punctured to obtain approximately two-third rate and three-fourth rate code schemes, CS2 and CS3 coding schemes. GPRS also supports an uncoded scheme, known as CS4 coding scheme.

Generally, channel coding schemes code and interleave data bits of a burst or a sequence of bursts to prevent their loss under degraded RF link conditions, for example, when RF links are exposed to fading. The number of coding bits used for channel coding of data bits corresponds to error detection accuracy, with higher number of coding bits providing higher bit error detection accuracy. For a given gross bit rate, a high number of coding bits, however,

reduces user bit rate, since coding bits reduce the number of user data bits that can be transmitted in a burst.

The communication channel typically introduces errors in sequence. In order to improve coding efficiency, the coded bits are interleaved, before transmission. The purpose of interleaving is to distribute the errors over several code words. The term perfect interleaving is used when the sequence of the received data bit errors are uncorrelated. The more uncorrelated the received data bits are at the receiver, the easier it is to recover lost data bits. On the other hand, if interleaving is not effective, large portions or blocks of transmitted data bits may be lost under degraded RF link conditions. Consequently, error correction algorithms may not be able to recover the lost data.

TDMA systems subdivide the available frequency band into one or several RF channels. The RF channels are divided into a number of physical channels corresponding to time slots in TDMA frames. Logical channels are mapped onto one or more physical channels, where modulation and channel coding schemes are specified. An RF link includes one or more physical channels that support the logical channels. In these systems, the mobile stations communicate with a plurality of scattered base stations by transmitting and receiving bursts of digital information over uplink and downlink RF channels.

The growing number of mobile stations in use today has generated the need for more voice and data channels within cellular telecommunication systems. As a result, base stations have become more closely spaced, with an

increase in interference between mobile stations operating on the same frequency in neighboring or closely spaced cells. Although digital techniques gain more useful channels from a given frequency spectrum, there still
5 remains a need to reduce interference, or more specifically to increase the ratio of the carrier signal strength to interference, (i.e., carrier-to-interference (C/I)) ratio. RF links that can handle lower C/I ratios are considered to be more robust than those that only can handle higher C/I
10 ratios.

Depending on the modulation and channel coding schemes, grade of service deteriorates more rapidly as link quality decreases. In other words, the data throughput or grade of service of more robust RF links deteriorates less
15 rapidly than those of less robust RF links. Higher level modulation schemes are more susceptible to link quality degradation than lower level modulation schemes. If a HLM scheme is used, the data throughput drops very rapidly with a drop in link quality. On the other hand, if a LLM scheme
20 is used, data throughput and grade of service does not deteriorate as rapidly under the same interference conditions.

Therefore, link adaptation methods, which provide the ability to dynamically change modulation scheme, channel
25 coding, and/or the number of used time slots, based on channel conditions, are used to balance the user bit rate against link quality. Generally, these methods dynamically adapt a system's combination of channel coding, modulation, and number of assignable time slots to achieve optimum
30 performance over a broad range of C/I conditions.

One evolutionary path for next generation of cellular systems is to use high-level modulation (HLM), e.g., 16QAM modulation scheme, to provide increased user bit rates compared to the existing standards. These cellular systems include enhanced GSM systems with GPRS extension, enhanced D-AMPS systems, International Mobile Telecommunication 2000 (IMT-2000), etc. A high level linear modulation, such as 16QAM modulation scheme, has the potential to be more spectrum efficient than, for example, GMSK, which is a low-level modulation (LLM) scheme. Because higher level modulation schemes require a higher minimum C/I ratio for acceptable performance, their availability in the system becomes limited to certain coverage areas of the system or certain parts of the cells, where more robust links can be maintained.

In order to provide various communication services, a corresponding minimum user bit rate is required. In voice and/or data services, user bit rate corresponds to voice quality and/or data throughput, with a higher user bit rate producing better voice quality and/or higher data throughput. The total user bit rate is determined by a selected combination of techniques for speech coding, channel coding, modulation scheme, and for a TDMA system, the number of assignable time slots per call.

Data services include transparent services and non-transparent services. Transparent services, which have a minimum link quality requirement, provide target user bit rates. A system that provides transparent communication services varies the gross bit rate to maintain a constant user bit rate with the required quality. Conversely, in

non-transparent services, for example, GPRS, the user bit rate may vary, because erroneously received data bits are retransmitted. Unlike non-transparent services, transparent services do not retransmit erroneously received data bits.

5 Therefore, transparent services have a constant point-to-point transmission delay, and non-transparent services have a non-constant point-to-point transmission delay.

A communication system may provide a data service through a number of RF links supporting different

10 combinations of channel coding, speech coding, and/or modulation schemes. For example, the system may provide a multimedia service using two or more separate RF links that separately provide audio and video signals. Under this scenario, one of the two RF links may use HLM scheme and the

15 other link may use LLM scheme. In order to provide a constant user bit rate in a TDMA system, lower level modulation schemes may use a higher number of time slots than higher level modulation schemes.

Moreover, digital communication systems must also

20 select a suitable combination of channel coding and modulation schemes based on link quality. For example, for a high quality link, higher level modulation or less channel coding results in higher user bit rate, which may be used advantageously by different communication services. For

25 example, in a non-transparent data service, user data throughput is increased. For a speech service, the increased user bit rate may be used for deploying an alternative speech coder with higher quality. Therefore, a system that supports multiple modulation and channel coding

30 schemes should provide sufficient flexibility for selecting

an optimum combination of modulation and channel coding schemes.

Conventional method for selecting an optimum combination of modulation and channel coding schemes assume
5 that the link quality parameters are perfectly known at a given instant. Usually, these methods determine link quality parameters by measuring, at predefined instances, one or more of received signal strength (RSS) or bit error rate (BER), etc. Using these instantaneous measurements,
10 these methods also assume that user quality as a function of link quality parameters is perfectly known for all combinations of modulation and channel coding schemes.

Because these parameters vary continuously, the mean measurement of link quality parameters do not give an
15 accurate indication of user quality, especially after a link with a different combination of modulation and channel coding schemes is selected. One method dynamically adapts user bit rate of a TDMA system to achieve optimum voice quality over a broad range of channel conditions. This
20 system continuously monitors link quality by making instantaneous measurements of a RF link's C/I ratio. The system dynamically adapts its combination of modulation and channel coding schemes and the number of assignable time slots to optimize voice quality for the measured conditions.
25 In addition, the system determines cost functions to derive at a cost of using RF links with different modulation and coding schemes to improve voice quality.

User quality, however, varies considerably with variations in link quality parameters. FIG. 1 shows link
30 performance of two modulation schemes, i.e., QPSK and 16QAM

schemes, which are exposed to three channel conditions: an Additive White Gaussian Noise (AWGN) channel condition, a fast Rayleigh Fading channel condition, and a slow Rayleigh fading channel condition. In FIG. 1, link performance is expressed in terms of BER. For a given C/I ratio, the AWGN channel provides the best performance, due to the lack of fading dips. In fast Rayleigh fading channel, where fading varies fast enough to make effective use of interleaving, link performance is degraded compared to the AWGN channel. In slow Rayleigh fading channel, where fading varies slowly such that interleaving is not effective, the worst link performance is obtained. Conventional methods use mean C/I ratio to determine the channel condition. As shown in FIG. 1, however, mean C/I ratio for different channel conditions may be the same, when link performance may be quite different. Therefore, more information is needed to accurately estimate link performance, if different combinations of modulation and channel coding is used.

An additional factor affecting user quality is time dispersion. Receiver equalizers can not effectively handle large time dispersions. As a result, link performance degrades, even when C/I ratio distribution remains the same. Accordingly, mean measurements of C/I ratio, BER or time dispersion alone are not sufficient for estimating performance of a selected link. Therefore, there exists a need for an effective link selection method in systems that support various modulation and channel coding schemes.

SUMMARY

The present invention that addresses this need is exemplified in a selection method that statistically characterizes combinations of available modulation and channel coding schemes using measured link quality parameters to determine which combination provides the best user quality. The method of the invention measures at least one link quality parameter of at least one RF link, for example, C/I ratio, BER, received signal strength, or time dispersion. Then, at least one channel characteristic measure is calculated based on the measured link quality parameter by computing both its mean value and variance. By introducing the variance of for example C/I ratio, it is possible to estimate the type of channel conditions a transmission is susceptible to. Consequently, it is possible to estimate how a change of modulation and/or channel coding scheme would effect the link quality. In an exemplary embodiment, the channel characteristic measure may be calculated for each one of available combinations of modulation and channel coding schemes of an RF link. Thereafter, a user quality estimator estimates user quality values, for example, user data throughput or speech quality values, based on the calculated channel characteristic measure. Finally, the present invention selects a combination of modulation and channel coding schemes on an RF link that provides the best user quality.

According to some of its more detailed features, the present invention maps the calculated channel characteristic measure with estimated user quality values of the supported combinations of modulation and channel coding

schemes. The mapping function may use simulation results, laboratory results, or results derived during normal operation of a communication system.

According to another aspect of the invention, the
5 selection method determines an optimal transmit power for each combination of modulation and channel coding schemes based on the measured link quality parameter. Thereafter, the user quality values are estimated based on the optimal transmit power. Also, data bursts are transmitted on the
10 selected RF link at the optimal transmit power.

Other features and advantages of the present invention will become apparent from the following description of the preferred embodiment, taken in conjunction with the accompanying drawings, which
15 illustrate, by way of example, the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram of the performance of two
20 variously modulated RF links under three different channel conditions.

FIG. 2 is a block diagram of a communication system which advantageously uses the present invention.

FIG. 3 is a diagram of a subdivided RF channel
25 that is used in the communication system of FIG. 2.

FIG. 4 is a diagram of a normal transmission burst transmitted on the RF channel of FIG. 3.

FIG. 5 is a block diagram of a mobile unit used in the communication system of FIG. 2.

FIG. 6 is a block diagram of a radio base station used in the communication system of FIG. 2.

FIG. 7 is a block diagram of a radio transceiver used in the base station of FIG. 6.

5 FIG. 8 is a flow chart of a link selection method according to an exemplary embodiment of the invention.

FIG. 9. is a block diagram of the selection method of FIG. 8.

10 FIG. 10 is a flow chart of a power selection scheme according to another aspect of the invention.

FIG. 11 is a graph of link performances of two combinations of channel coding and modulation schemes.

DETAILED DESCRIPTION

15 Referring to FIG. 2, a communication system 10 according to an exemplary embodiment of the present invention supports multiple modulation schemes. In an exemplary embodiment of the invention, the system 10 supports three modulation schemes: a first LLM (LLM1) scheme, a second LLM (LLM2) scheme, and a HLM scheme. LLM1
20 scheme is a non-linear modulation scheme, such as GMSK modulation scheme used in GSM systems. LLM2 scheme is a linear modulation scheme, such as QPSK. Finally, HLM scheme is a higher level linear modulation schemes, for example,
25 16QAM scheme, that could be supported by the second generation of enhanced GSM systems, which as of yet are not standardized.

The communication system 10 also supports the channel coding schemes of GSM's GPRS extension. The system
30 10, therefore, supports CS1, CS2, CS3, and CS4 channel

coding schemes. The system 10 supports various combinations of modulation and channel coding schemes on a plurality of RF links. Although, the system 10 is described with reference to the above specified exemplary modulation and channel coding schemes, it should be noted that a wide range of modulation and coding schemes may be used to implement the present invention.

The mode of operation of GSM communication systems is described in European Telecommunication Standard Institute (ETSI) documents ETS 300 573, ETS 300 574 and ETS 300 578, which are hereby incorporated by reference. Therefore, the operation of the GSM system is described to the extent necessary for understanding of the present invention. Although, the present invention is described as embodied in a GSM system, those skilled in the art would appreciate that the present invention could be used in a wide variety of other digital communication systems, such as those based on PDC or D-AMPS standards and enhancements thereof. The present invention may also be used in CDMA or a hybrid of CDMA and TDMA communication systems.

The communication system 10 covers a geographical area that is subdivided into communication cells, which together provide communication coverage to a service area, for example, an entire city. Preferably, the communication cells are patterned according to a cell pattern that allows some of the spaced apart cells to use the same uplink and downlink RF channels. In this way, the cell pattern of the system 10 reduces the number of RF channels needed to cover the service area. The system 10 may also employ frequency hopping techniques, for example, to avoid "deadspots."

Initial selection of modulation scheme would preferably depend on either measured or predicted link quality parameters of a new RF link. Alternatively, the initial selection may be based on a predefined cell parameter. Due to a possible difference in link robustness for LLM1, LLM2, and HLM schemes, a mobile station 12 continues to use LLM1 scheme until the channel characteristic allows the use of other schemes, in which case a link adaptation procedure is initiated to switch modulation scheme from LLM1 scheme to LLM2, or HLM scheme.

When no information is transferred to or from a mobile station 12, for example, during idle states or wait states of GPRS, the mobile station 12 preferably measures link quality parameters of different RF links. For instance, the mobile station 12 measures the interference on RF links that are candidates for use in the future as well as the received signal strength of its current link. The measurement results are used to determine a distribution of channel characteristic measures. These measurements serve as the basis for deciding which combination of modulation and channel coding schemes to use subsequently.

According to the present invention, during an ongoing communication, user quality values are estimated based on channel characteristics, which are expressed in terms of variations and mean values of link quality parameters. The channel characteristics are derived based on measurements of link quality parameters over a predefined period. In this way, the system 10 estimates user quality values provided by available combinations of modulation and channel coding schemes of one or more RF links. By

comparing the estimated user quality values of these combinations, the present invention selects a modulation and channel coding combination on an RF link that provides the best user quality value.

5 For example, for providing a non-transparent service, the system 10 estimates user quality values of available combinations of modulation and channel coding schemes on the one or more RF links in terms of data throughput S. For a predefined time period, the system 10
10 continuously measures link quality parameters and calculates their mean values and variances. The present invention relies on statistical measures to characterize an RF link. Although the exemplary embodiment uses mean values and variances, other statistical measures may also be used, for
15 example, standard deviation, median, etc. The system 10 calculates the mean values of such link quality parameters as C/I ratio or BER values that are obtained over the predefined time period. Based on measured link quality parameters over the predefined time period, the system 10
20 also determines the variances of one or more of the link quality parameters. Based on the variances, the system 10 estimates the data throughputs S for all combinations of modulation and channel coding schemes over one or more RF links. The system then selects a new combination of
25 modulation and channel coding schemes on a RF link, if switching to the new combination on that RF link provides a higher data throughput S than that provided by a current combination.

For a speech service, the system 10 may use a
30 different user quality value measure than the data

throughput S used for a non-transparent data service. Preferably, the user quality value in speech service is expressed in terms of a voice quality value Q , which may be based on estimated frame erasure rate (FER) and/or residual user bit error rate (RBER) originated from the use of various speech coding schemes. Under this arrangement, the present invention estimates voice quality values Q for different combinations of modulation and channel coding schemes. Then, the system 10 selects a combination that provides the best estimated voice quality value.

The system 10 is designed as a hierarchical network with multiple levels for managing calls. Using an allocated set of uplink and downlink RF links a number of mobile stations 12 operating within the system 10 participate in calls using allocated time slots. At a high hierarchical level, a group of Mobile Service Switching Centers (MSCs) 14 are responsible for the routing of calls from an originator to a destination. In particular, they are responsible for setup, control and termination of calls. One of the MSCs 14, known as the gateway MSC, handles communication with a Public Switched Telephone Network (PSTN) 18, or other public and private networks.

Different operators support different communication standards with different modulation and channel coding schemes. The same operator may also support different modulation and channel coding schemes in different cells. For example, one operator may support LLM1 modulation scheme and CS4 channel coding scheme only, whereas, another operator may support all of the modulation and channel coding schemes. The communication system 10

uses the present invention to select a combination of modulation and channel coding schemes that provide the best user quality value.

At a lower hierarchical level, each one of the
5 MSCs 14 are connected to a group of base station controllers (BSCs) 16. The primary function of a BSC 16 is radio resource management. For example, based on reported received signal strength at the mobile stations 12, the BSC 16 determines whether to initiate a hand over. Under the
10 GSM standard, the BSC 16 communicates with a MSC 14 under a standard interface known as the A-interface, which is based on the Mobile Application Part of CCITT Signaling System No. 7.

At a still lower hierarchical level each one of
15 the BSCs 16 controls, a group of base transceiver stations (BTSS) 20. Each BTS 20 includes a number of TRXs that use the uplink and downlink RF channels to serve a particular common geographical area. The BTSS 20 primarily provide the RF links for the transmission and reception of data bursts
20 to and from the mobile stations 12 within their designated cell. In an exemplary embodiment, a number of BTSS 20 are incorporated into a radio base station (RBS) 22. The RBS 22 may be configured according to a family of RBS-2000 products, which is offered by Ericsson, the assignee of the
25 present invention.

With reference to FIG. 3, an RF channel 26 (uplink or downlink) is divided into repetitive time frames 27 during which information are communicated. Each frame 27 is further divided into time slots 28 that carry packets of
30 information. Speech or data is transmitted during time slots

designated as traffic channels (TCH_1, \dots, TCH_n). All signaling functions pertaining to call management in the system, including initiations, hand overs, and termination are handled via control information transmitted over control channels.

The mobile stations 12 use slow associated control channels (SACCHs) to transmit associated control signals, such as an RX-LEV signal, which corresponds to the received signal strength at the mobile station and RX-QUAL signal, which is a measure of various levels of bit error rate at the mobile station 12, as defined by the GSM standard. Fast associated control channels (FACCHs) perform control functions, such as hand-overs, by stealing time slots allocated for TCHs.

The BSC 16 instructs the RBS 22 based on measures of channel characteristics of RF links between mobile stations 12 to the RBS 22. As described later in detail, the channel characteristics may be measured based on a number of parameters, including received signal strength, bit error rate, the multipath propagation property of the uplink RF channel, for example, time dispersion, or a combination of them.

The system 10 carries out the transmission of information during a time slot in a burst that contain a predefined number of coded bits. The GSM specification defines various types of bursts: normal burst (NB), frequency correction burst (FB), synchronization burst (SB), access burst (AB), and dummy burst. The normal burst, which has a duration of 576 μs , is used both during the traffic and some control signalling channels. The remaining bursts

are primarily used for access and maintaining signal and frequency synchronization within the system.

As shown in FIG. 4, a normal burst 29 includes two separate data portions 30 during which digital data bits are communicated. The normal burst also includes tail and guard sections 31 and 32 as shown. Among other things, the guard section 32 is used to allow for up-ramping of the burst and for down-ramping of the bursts. The tail section 31 is used for demodulation purposes. All burst transmissions, except dummy burst transmissions, include training sequences. The training sequences are patterned with predefined autocorrelation characteristics. During demodulation process, the auto correlation characteristic of the training sequence helps in the synchronization of the received bit sequences over an RF channel. In the normal burst 29, a training sequence 33 is positioned in the middle of the burst between its data portions.

In order to compensate for propagation delays over RF links, the communication system 10 uses a time alignment process by which the mobile stations 12 align their burst transmissions to arrive at the BTSs 20 in proper time relationship relative to other bursts transmissions. As described later, the mobile station 12 and the RBS 22 incorporate equalizers, which correlate received baseband bit sequences over the uplink or downlink RF channels with the training sequences, to provide correlator responses that correspond to the properties of multipath propagation. Based on the correlator responses, the receiver section of the BTS 20 generates a timing advance (TA) parameter. The mobile station 12 uses the TA parameter, which is

transmitted from the RBS 22, for advancing or retarding its burst transmissions relative to a time reference.

With reference to FIG. 5, the block diagram of a mobile station 12 is shown. The mobile station 12 includes a receiver section 34 and a transmitter section 36, which are coupled to an antenna 38 through a duplexer 39. The antenna 38 is used for receiving and transmitting RF signals to and from the BTS 20 over allocated uplink and downlink RF channels. The receiver section 34 includes an RF receiver 40, which includes a local oscillator 41, a mixer 42, and selectivity filters 43 arranged in a well known manner, for down-converting and demodulating received signals to a baseband level. The RF receiver 40, which is tuned by the local oscillator 41 to the downlink channel, also provides an RX-LEV signal on line 44 that corresponds to the received signal strength at the mobile station 12.

The RF receiver provides a baseband signal to a demodulator 46 that demodulates coded data bits representing the received speech, data and signaling information. Depending on the type of mobile station 12, the demodulator 46 can support one or more demodulation schemes corresponding to LLM1, LLM2, and HLM schemes. For example, the demodulator of a mobile station 12 subscribed to an operator that supports LLM1 scheme may be capable of demodulating LLM1 modulated signals only. On the other hand, the demodulator of a mobile station 12 subscribed to an operator that supports all of the three modulation schemes is preferably capable of demodulating LLM1, LLM2, and HLM schemes.

As described above, the demodulator 46 includes an equalizer (not shown) that processes the coded bit pattern disposed on the training sequences, to provide correlator response that are used for demodulation of the baseband signal. The equalizer uses the correlator responses to determine the most probable bit sequence for demodulation. As defined by the GSM specification, a channel decoder/de-interleaver 50 also provides an RX-QUAL signal on line 48, which is a measure of various levels of bit error rate at the mobile station 12. The mobile station 12 reports the RX-QUAL signal and the RX-LEV signal to the BSC 16 on a SACCH channel.

The channel decoder/de-interleaver 50 decodes and de-interleaves the demodulated signal. The channel decoder/de-interleaver 50 may use a wide variety of channel decoding schemes, including CS1-CS4 decoding schemes. The speech data bits are applied to a speech decoder 52 that decodes the speech pattern using one of a variety of supported speech decoding schemes. After decoding, the speech decoder 52 applies an analog speech signal to a output device 53, e.g., a speaker, via an audio amplifier 54. The channel decoder 50 provides the decoded data and signalling information to a microprocessor 56 for further processing, for example, displaying the data to a user.

The transmitter section 36 includes an input device 57, e.g., a microphone and/or keypad, for inputting voice or data information. According to a specified speech/data coding techniques, a speech coder 58 digitizes and codes the voice signals according to a variety of supported speech coding schemes. A channel

coder/interleaver 62 codes the uplink data according to a specified coding/interleaving algorithms, including CS1-CS4 coding schemes. The channel coder/interleaver 62 provides an uplink baseband signal to a modulator 64. The modulator 5 64 modulates the uplink baseband signal according to one or more of supported modulation schemes. Similar to the demodulator 46, the modulator 64 of the mobile station 12 may support one or more of LLM1, LLM2, and HLM schemes.

The modulator 64 applies the coded signal to an 10 up-converter 67, which receives a carrier signal from the up-converted signal local oscillator 41. An RF amplifier 65 amplifies the up-converted signal for transmission through the antenna 38. A well known frequency synthesizer 66, under the control of the microprocessor 56, supplies the 15 operating frequency information to the local oscillator 41. The microprocessor 56 causes the mobile station 12 to transmit the RX-QUAL and RX-LEV parameters to the RBS 22 over the SACCH.

Referring to FIG. 6, an exemplary block diagram of 20 the RBS 22 is shown to include a plurality of BTSs 20 that serve different geographical areas. Through a timing bus 72, the BTSs 20 are synchronized with each other. Voice and data information are provided to and from the RBS 22 through a traffic bus 74 that may be coupled, through the A-bis 25 interface, to a public or private voice and data transmission line, such as a T1 line (not shown). Each BTS 20 includes TRXs 75 and 76 that communicate with the mobile station 12. As shown, two antennas designated as 24A and 24B are spaced accordingly to cover cells 77 and 78. The 30 TRXs 76 are coupled to the antennas 24 through

combiner/duplexers 80 that combine downlink transmission signals from the TRXs 76 and distribute the uplink received signals from the mobile station 12. The RBS 22 also includes a base station common function (BCF) block 68 that controls the operation and maintenance of the RBS 22.

Referring to FIG. 7, a block diagram of a TRX 76 is shown. The TRX 76 includes a transmitter section 86, a receiver section 87, a baseband processor 88 and a TRX controller 90. Through a corresponding antenna 24 (shown in FIG. 6), the receiver section 87 receives uplink signals from the mobile station 12. A down-conversion block 91 down-converts the received signal. After down-converting the received signals, the receiver section 87 samples its phase and magnitude, via a sampler block 92, to provide received bit sequence to the baseband processor 88. An RSSI estimator 94 provides an RSSI signal on line 95, which is a measure of the received signal strength. The RSSI estimator 94 may also measure noise disturbance levels during idle channels. The TRX controller 90, which is coupled to the traffic bus 74, processes the commands received from the BSC 16 and transmits TRX related information, such as various TRX measurements, to the BSC 16. Under this arrangement, the TRX 76 periodically reports the RSSI signal and noise disturbance levels to the BSC 16.

The baseband processor 88 includes a demodulator 96 that receives uplink baseband data from the receiver section 87. The demodulator 96 generates correlator responses that are processed in a well known manner to retrieve the uplink baseband data. Similar to the mobile station 12, the demodulator may support demodulation of

signals that are modulated using one or more of LLM1, LLM2 or HLM schemes. The uplink baseband data is applied to a channel decoder 97 that decodes the baseband signal according to one or more supported channel decoding scheme, including CS1-CS4 decoding schemes. The channel decoder 97 places the decoded baseband signal on the traffic bus 78, for further processing by the BSC 16.

When transmitting downlink baseband data, the baseband processor 88 receives properly coded data or digitized speech information from the BSC 16 over the traffic bus 74 and applies them to a channel coder 102 that codes and inter-leaves speech and data according to one or more of supported channel coding schemes, including CS1-CS4 channel coding schemes. The transmitter section includes a modulator 104 that modulates the supplied data bits according to one or more of LLM1, LLM2, and HLM schemes. The modulator 104 provides downlink baseband signals to an up-conversion block 106 for up-conversion. A power amplifier 108 amplifies the up-converted signal for transmission through a corresponding antenna.

The system 10, for example, uses one or a combination of the RX-QUAL, RX-LEV, or time dispersion parameters, which are measures of link quality parameters of an RF link, to select an optimum combination of modulation and channel coding on an RF link. The system 10 also uses these parameters to decide whether a link adaptation procedure should be initiated or not. The BSC 16 compares the channel characteristic parameter to corresponding thresholds to determine whether to initiate a link

adaptation procedure within coverage areas that support LLM1, LLM2, and HLM schemes.

Referring to FIG. 8, a flow chart of a method for selecting a combination of modulation and channel coding schemes on an RF link according to an exemplary embodiment of the present invention is shown. In this exemplary embodiment, it is assumed that system 10 provides a non-transparent data service, for example, a packet data service under GPRS, in which data blocks, the smallest retransmittable units, are transmitted and erroneously received blocks are re-transmitted according to an Automatic Repeat Request (ARQ) scheme.

The selection method starts by measuring link quality parameters of an RF link at a receiver that may be in the mobile station 12 or a BTS 20, block 801. If more than one RF links are available, the selection method may measure link quality parameters of all available links as well. Examples of link quality parameter measurements include C/I ratio, received signal strength, time dispersion on burst level, and raw BER on block level. The measurements are processed to determine the distribution of the channel characteristic measures. For example, the channel characteristic measures, which may be the distribution of link quality parameters, can be calculated as mean values and variances of the link quality parameters, block 803. The processed measurement results are reported to a link quality estimator, block 805.

In a preferred embodiment, the link quality estimator performs a mapping function f_i , which maps the channel characteristic measures with estimated user quality

values of each one of the supported combinations of modulation and channel coding schemes i , block 807. For example, mapping function f_i calculates the mean value and variance of raw BER_i based on measurement results, and then, based on the mean and variance value estimates $BLER_i$. The mapping functions may be implemented using a table that is initially constructed based on empirical results, such as simulation results, or experimental results, such as laboratory results, of the various combinations of modulation and channel coding schemes. Alternatively, the table may include results tuned based on actual measurements during the normal operation of the system 10.

In this exemplary embodiment, $BLER$ estimates are used for calculating user quality values in terms of data throughputs S_i for each one of the combinations of modulation and coding schemes, block 809. The user quality values are used for selecting an optimum combination of modulation and channel coding schemes on an RF link by comparing the data throughputs S_i , block 811. If the data throughput of a new combination, other than the one currently used is significantly higher, a link adaptation procedure is initiated to switch to the new combination.

For selecting the combination of modulation and channel coding scheme on an uplink RF link, the present invention performs all of the above specified steps at the RBS 22. For selecting the combination of modulation and channel coding scheme on a downlink RF link, the mobile station 12 performs the steps of measuring link quality parameters and calculating mean values and variances and reporting the channel characteristic measures to the RBS 22.

The RBS 22 then performs the link quality estimation function and decides whether a new combination of modulation and channel coding schemes on an RF link should be selected or not. For the downline, the link quality estimation may
5 of course also be performed in the mobile station.

FIG. 9 shows an exemplary block diagram of a means for estimating data throughput for N combinations of modulation and coding schemes. A channel characteristic estimator block 112 receives the link quality parameter
10 measurements, e.g. C/I ratio, received signal strength, raw BER, and time dispersion parameter. Based on the measured link quality parameters, the channel characteristic estimator block 112 provides their mean values and
variances. A user quality value estimator block 114, which
15 operates based on previously obtained statistical link performance results or actual system measurements, provides estimate of $BLER_1$ through $BLER_N$. Based on nominal data bit rates R_i , a converter block 116 converts estimates of $BLER_1$ through $BLER_N$ to estimates of S_1 through S_N by using Equation
20 (1):

$$(1) \quad S_i = R_i (1 - BLER_i).$$

Based on the data throughputs S_i , a selector block 118 selects an optimum combination of modulation and channel
25 coding schemes on an RF link.

According to another aspect of the invention, a power control scheme is used in combination with the above described link selection method. Assuming that a transmitter has a power dynamic range between P_{min} and P_{max} ,
30 this aspect of the invention selects an optimum power level,

$P_{opt} \in [P_{min}, P_{max}]$, for each combination of modulation and channel coding schemes. The optimal power is based on a C/I target (C/I_{des}) for each combination, which may be based on a target user quality value, such as BLER target ($BLER_{des}$).

5 Referring to FIG. 10, a flow chart of the power control scheme of this aspect of the invention is shown. The system 10 measures the mean value of C/I ratio (or other link quality parameters), for example using the measure obtained from step 803 of FIG. 8, block 101. Based on the
10 mean C/I ratio, the system 10 calculates an optimal power P_{opt} using Equation (2):

$$(2) \quad P_{opt(i)} = P + (C/I_{des(i)} - \text{mean } C/I),$$

where P is transmit power at a time t and $C/I_{des(i)}$ ratio is a target C/I ratio for achieving a desired user quality
15 value for a combination of modulation and channel coding schemes i , block 103. For example, $C/I_{des(i)}$ ratio may be a ratio that provides the target $BLER_{des(i)}$ for different combinations of modulation and channel coding schemes. Then, the optimal power P_{opt} is truncated for each
20 combination of modulation and channel coding scheme using Equation (3):

$$(3) \quad P_{opt(i)} = \min[P_{max}, \max(P_{min}, P_{opt(i)})].$$

The truncation step, block 105, allows for selection of a combination of modulation and channel coding scheme that
25 provides the best user quality value, provided that the transmitter can produce the selected P_{opt} without exceeding its P_{max} . If the calculated P_{opt} is higher than the P_{max} , the system 10 sets the power of the transmitter at P_{max} . On the other hand, if the calculated P_{opt} is less than the P_{min} , the
30 system 10 sets the power of the transmitter at P_{min} . Then,

for all combinations of modulation and channel coding schemes, the system 10 calculates, block 107, the mean C/I_i ratio using Equation 4:

$$(4) \quad \text{mean } C/I_i = \text{mean } C/I + (P_{\text{opt } (i)} - P).$$

5 This step estimates a corresponding mean C/I_i for each combination of modulation and channel coding scheme by taking into account the dynamic range of the transmit power between P_{max} and P_{min} . Once an optimum combination of modulation and channel coding schemes is selected, using for
10 example, the steps described in blocks 805-811, the system 10 transmits on a selected RF link using the optimum combination at the optimal power P_{opt} , blocks 109 and 11.

Referring to FIG. 11, a graph of link performances of two combinations of modulation and channel coding schemes
15 is shown to describe an exemplary power control scheme according to the above described aspect of the invention. At a given time t , the transmit power of the transmitter, which, for example, has a dynamic range between $P_{\text{min}}=5$ dBm and $P_{\text{max}}=33$ dBm, is assumed to be at $P_t=20$ dBm. The measured
20 C/I_t ratio is assumed to be 8 dB. The target C/I_{des} ratio is determined that gives a desired user quality. For example, C/I_{des} ratio is 12 dB for the first combination (shown with Graph 1), and it is 27 dB for the second combination (shown with Graph 2). In order to achieve the C/I_{des} ratio for the
25 first and second combinations, the transmit power must be increased by 4 dB and 19 dB, respectively. Hence, for the first combination, P_{opt} is equal to 24 dBm, and for the second combination P_{opt} is 39 dbm, which is beyond P_{max} . In this case, the system 10 sets the transmit power to P_{max} of
30 33 dBm and calculates the C/I ratio according to Equation

(4). Based on the measured C/I ratio at P_{max} , a link providing the best user quality value is selected.

From the foregoing it would be appreciated that the present invention significantly facilitates RF link selection process in systems that supports multiple modulation and coding schemes. By statistically characterizing RF links in terms of distribution and variances of link quality parameters, the present invention provides a more effective link selection process. In this way, the present invention improves communication quality of systems that support multiple combinations of modulation and coding schemes.

Although the invention has been described in detail with reference only to a preferred embodiment, those skilled in the art will appreciate that various modifications can be made without departing from the invention. Accordingly, the invention is defined only by the following claims which are intended to embrace all equivalents thereof.

What is claimed is:

1. In a communication system, a method for selecting a combination of modulation and channel coding
5 scheme from a plurality of combinations of modulation and channel coding schemes comprising the steps of:
measuring at least one link quality parameter of an RF link;
calculating at least one channel
10 characteristic measure based on the measured at least one link quality parameter;
estimating user quality values for each one of the combinations of modulation and channel coding schemes based on the calculated channel characteristic measure; and
15 selecting a combination of modulation and channel coding schemes on an RF link that provides the best user quality value.
2. The method of claim 1, wherein the at least
20 one link quality parameter is selected from one of a C/I ratio, BER, received signal strength, or time dispersion.
3. The method of claim 1, wherein the step of calculating the at least one channel characteristic measure
25 includes the step of calculating a variance of the at least one measured link quality parameter.
4. The method of claim 3, wherein the step of calculating the at least one channel characteristic measure

includes the step of calculating a mean value of the at least one measured link quality parameter.

5 5. The method of claim 1, wherein the step of estimating user quality values includes the step of mapping the at least one calculated channel characteristic measure with estimated user quality values of supported combinations of modulation and channel coding schemes.

10 6. The method of claim 1, wherein the user quality values are estimated using simulation results or laboratory results.

15 7. The method of claim 1, wherein the user quality values are estimated using results derived during normal operation of the communication system.

20 8. The method of claim 1, wherein the user quality values include a user data throughput.

 9. The method of claim 8, wherein the step of estimating user quality values includes the step of estimating block error rates.

25 10. The method of claim 9, wherein the step of estimating user quality values includes the step of computing estimates of the user data throughput based on the estimated block error rates and nominal bit rates.

11. The method of claim 1, wherein the user quality values include speech quality values.

12. The method of claim 11, wherein said step of
5 estimating user quality values includes the step of estimating the speech quality values originating from the use of different speech coding schemes.

13. The method of claim 1 further including the
10 step of determining an optimal transmit power for each combination of modulation and channel coding schemes based on the at least one measured link quality parameter, wherein the optimal transmit power is limited by a dynamic range of a power transmitter.

14. The method of claim 13 further including the
15 step of transmitting on the RF link at the optimal transmit power.

15 The method of claim 1, wherein the step of
20 selecting a combination of modulation and channel coding schemes is performed during idle states or wait states.

16. In a communication system, a method for
25 selecting a combination of modulation and channel coding schemes from a plurality of combinations of modulation and channel coding schemes comprising the steps of:

communicating data using a non-transparent
service over an RF link;

measuring at least one link quality parameter of the RF link;

calculating at least one channel characteristic measure based on the at least one measured link quality parameter;

estimating user data throughput for each combination of modulation and channel coding schemes based on the calculated channel characteristic; and

selecting a combination of modulation and channel coding schemes of the RF link from the plurality of combinations of modulation and channel coding schemes that provides the best user data throughput.

17. The method of claim 16, wherein the at least one link quality parameter is selected from one of a C/I ratio, BER, received signal strength, or time dispersion.

18. The method of claim 16, wherein the step of calculating the at least one channel characteristic measure includes the step of calculating a variance of the measured at least one link quality parameter.

19. The method of claim 18, wherein the step of calculating the at least one channel characteristic measure includes the step of calculating a mean value of the at least one measured link quality parameter.

20. The method of claim 16, wherein the step of estimating user quality values includes the step of mapping the calculated channel characteristic measure with estimated

user data throughput of supported combinations of modulation and channel coding schemes.

21. The method of claim 16, wherein the user data
5 throughput is estimated using simulation results or
laboratory results.

22. The method of claim 16, wherein the user data
throughput is estimated using results derived during normal
10 operation of the communication system.

23. The method of claim 16, wherein said step of
estimating user data throughput includes the step of
estimating block error rates and computing user data
15 throughput based on the estimated block error rates and
nominal bit rates.

24. The method of claim 16 further including the
step of determining an optimal transmit power for each
20 combination of modulation and channel coding schemes based
on the measured link quality parameter and, wherein the
optimal transmit power is limited by a dynamic range of a
power transmitter.

25. The method of claim 24 further including the
step of transmitting on the RF link at the optimal transmit
power.

26. A communication system that communicates over RF links that support different combinations of modulation and channel coding schemes comprising:

means for measuring at least one link quality
5 parameter of an RF link;

means for calculating at least one channel characteristic measure based on the measured at least one link quality parameter;

means for estimating user quality values
10 based on the calculated channel characteristic and the corresponding combinations of the modulation and channel coding schemes; and

means for selecting a combination of modulation and channel coding schemes on an RF link that
15 provides the best user quality value.

27. The communication system of claim 26, wherein the at least one link quality parameter is selected from one
20 of a C/I ratio, BER, received signal strength, or time dispersion.

28. The communication system of claim 26, wherein the means for calculating the at least one channel
25 characteristic measure calculates a variance of the measured at least one link quality parameter.

29. The communication system of claim 28, wherein the means for calculating the at least one channel

characteristic measure calculates a mean value of the measured at least one link quality parameter.

30. The communication system of claim 26, wherein
5 the means for estimating user quality values includes means for mapping the at least one calculated channel characteristic measure with the supported combinations of modulation and channel coding schemes.

10 31. The communication system of claim 26, wherein the user quality values are estimated using simulation results.

15 32. The communication system of claim 26, wherein the user quality values are estimated using results derived during normal operation of the communication system.

20 33. The communication system of claim 26, wherein the user quality values include a user data throughput.

34. The communication system of claim 26, wherein the means for estimating user quality values estimates block error rates.

25 35. The communication system of claim 26, wherein the means for estimating user quality values computes estimates of the user data throughput based on the estimated block error rates and nominal bit rates.

36. The communication system of claim 26, wherein the user quality values include speech quality values.

37. The communication system of claim 36, wherein
5 the means for estimating user quality values estimates the speech quality values originating from the use of different speech coding schemes.

38. The communication system of claim 36 further
10 including a power transmitter for transmitting on the RF link and means for determining an optimal transmit power for each combination of modulation and channel coding schemes based on the measured link quality parameter, wherein the optimal transmit power is limited by a dynamic range of the
15 power transmitter.

39. In a communication system that provides for communication between a mobile station and a base station over uplink and downlink RF links, a method for selecting a
20 combination of modulation and channel coding schemes from a plurality of combinations of modulation and channel coding schemes comprising the steps of:

measuring at least one link quality parameter of an RF link at the base station;

25 calculating at least one channel characteristic measure based on the measured link quality parameter at the base station;

estimating user quality values for each one of the combinations of modulation and channel coding schemes
30 based on the calculated channel characteristic and the

corresponding combinations of the modulation and channel coding scheme supported at the base station; and

selecting a combination of modulation and channel coding schemes on the RF link that provides the best user quality value.

40. In a communication system that provides for communication between a mobile station and a base station over uplink and downlink RF links, a method for selecting a combination of modulation and channel coding schemes from a plurality of combinations of modulation and channel coding schemes comprising the steps of:

measuring at least one link quality parameter of an RF link at the mobile station;

calculating at least one channel characteristic measure based on the at least one measured link quality parameter at the mobile station;

reporting the calculated channel characteristic measure to the base station;

estimating user quality values for each one of the combinations of modulation and channel coding schemes based on the calculated channel characteristic and the corresponding combinations of the modulation and channel coding scheme supported at the base station; and

selecting a combination of modulation and channel coding schemes on the RF link that provides the best user quality value.

41. In a communication system that provides for communication between a mobile station and a base station over uplink and downlink RF links, a method for selecting a combination of modulation and channel coding schemes from a plurality of combinations of modulation and channel coding schemes comprising the steps of:

measuring at least one link quality parameter of an RF link at the mobile station;

calculating at least one channel characteristic measure based on the at least one measured link quality parameter at the mobile station;

estimating user quality values for each one of the combinations of modulation and channel coding schemes based on the calculated channel characteristic and the corresponding combinations of the modulation and channel coding scheme supported at the base station; and

selecting a combination of modulation and channel coding schemes on the RF link that provides the best user quality value.

FIG. 1

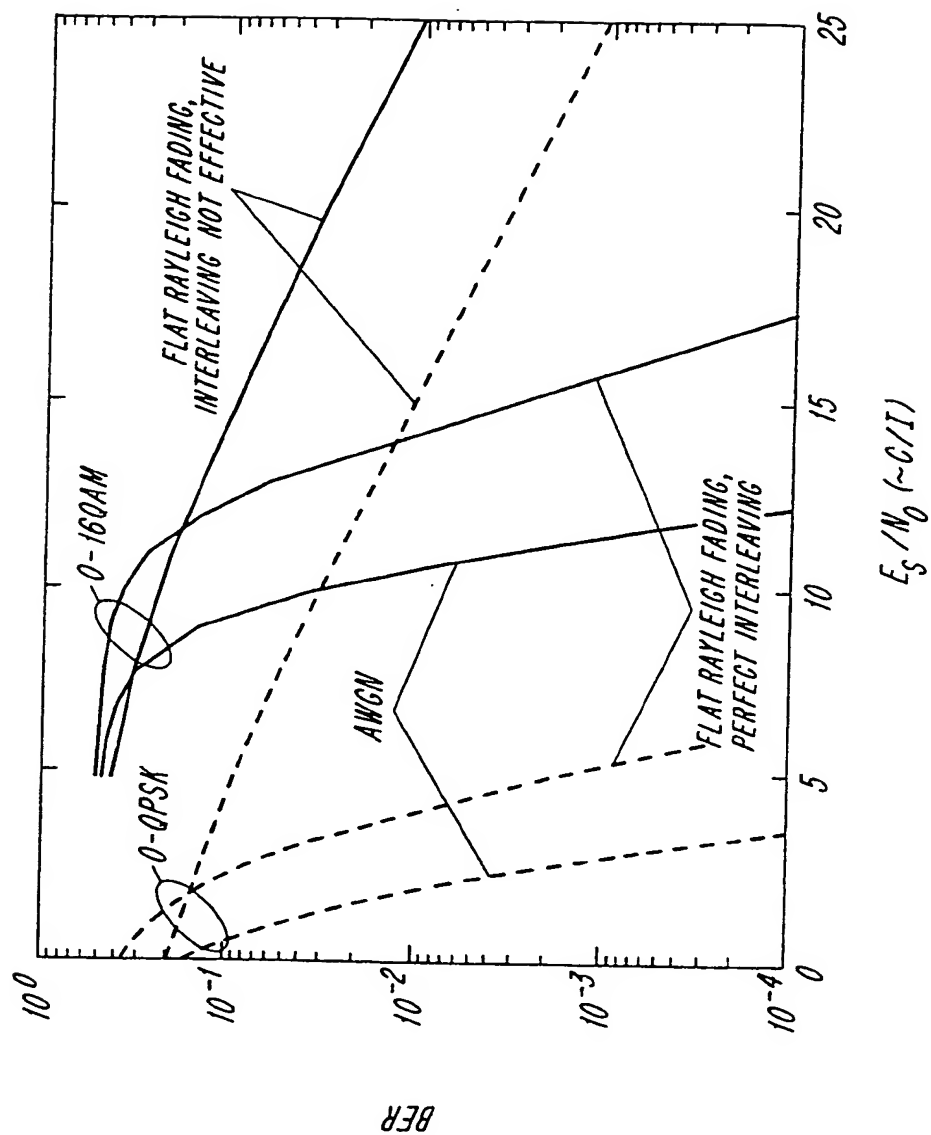
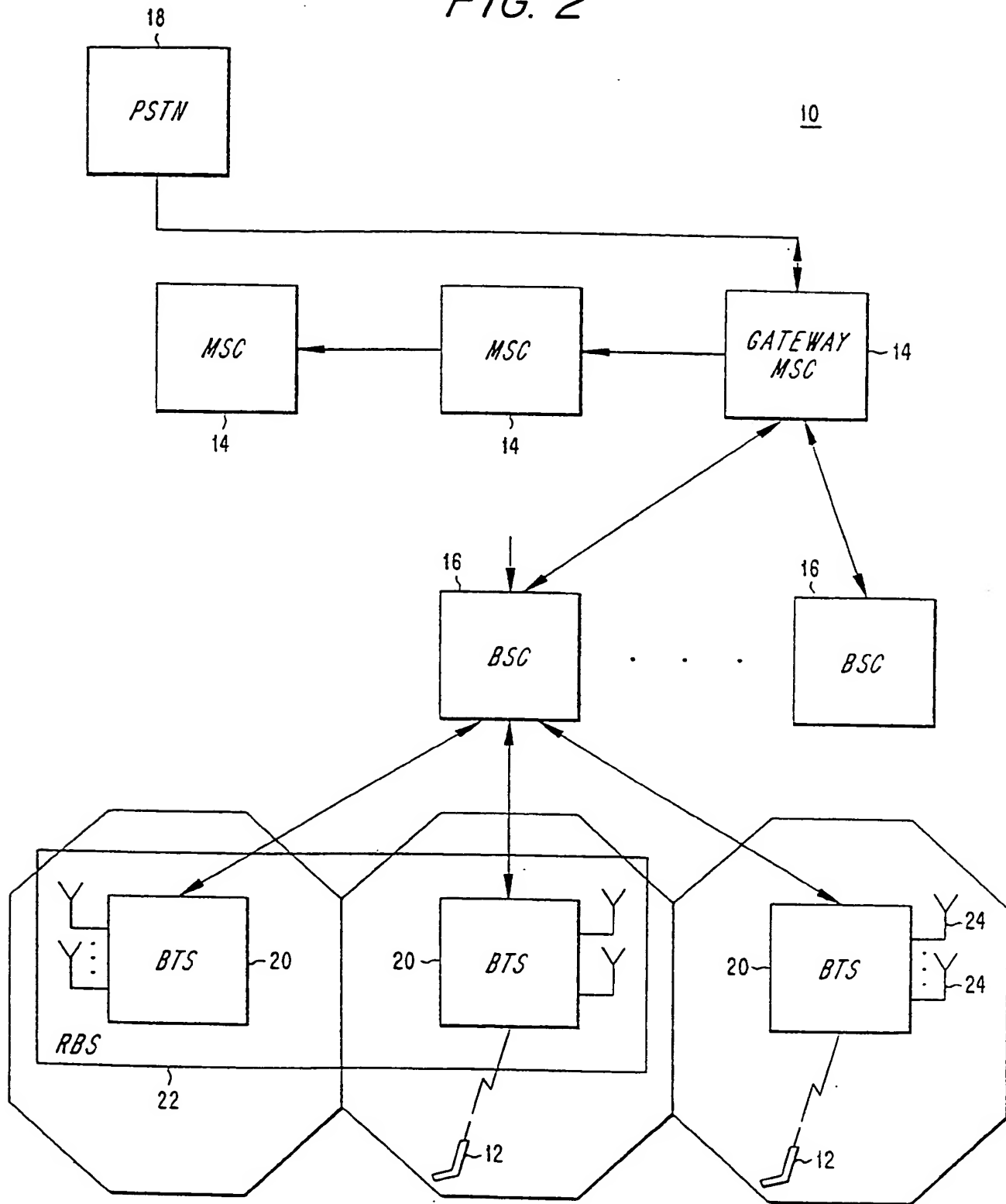


FIG. 2



3/10

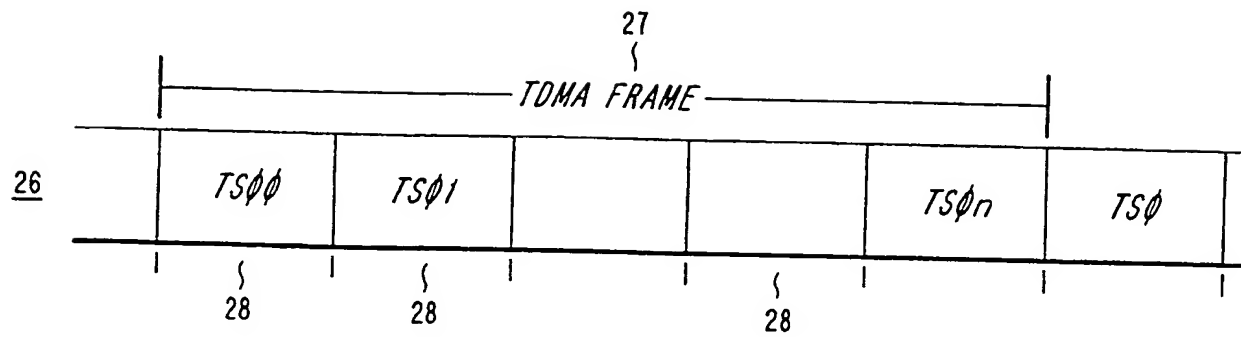


FIG. 3

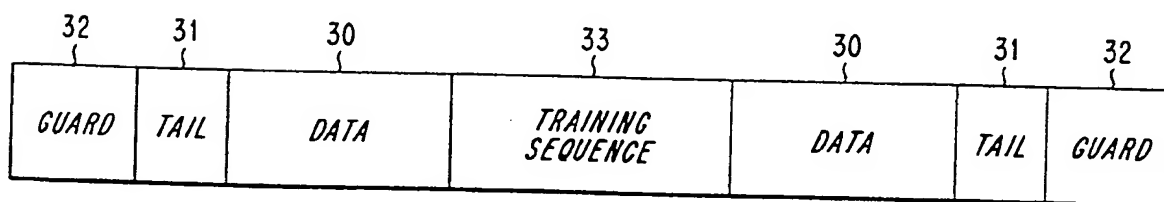


FIG. 4

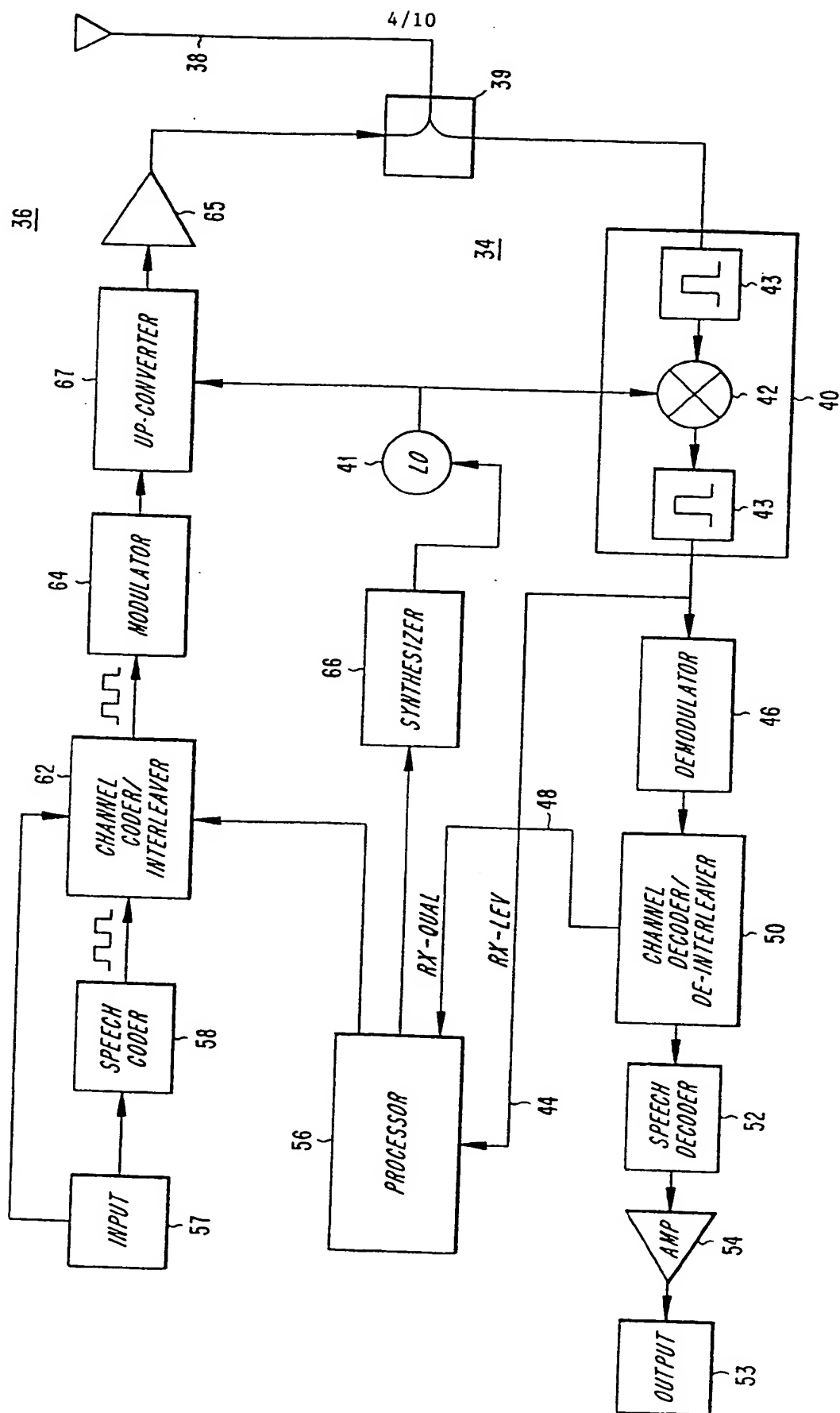
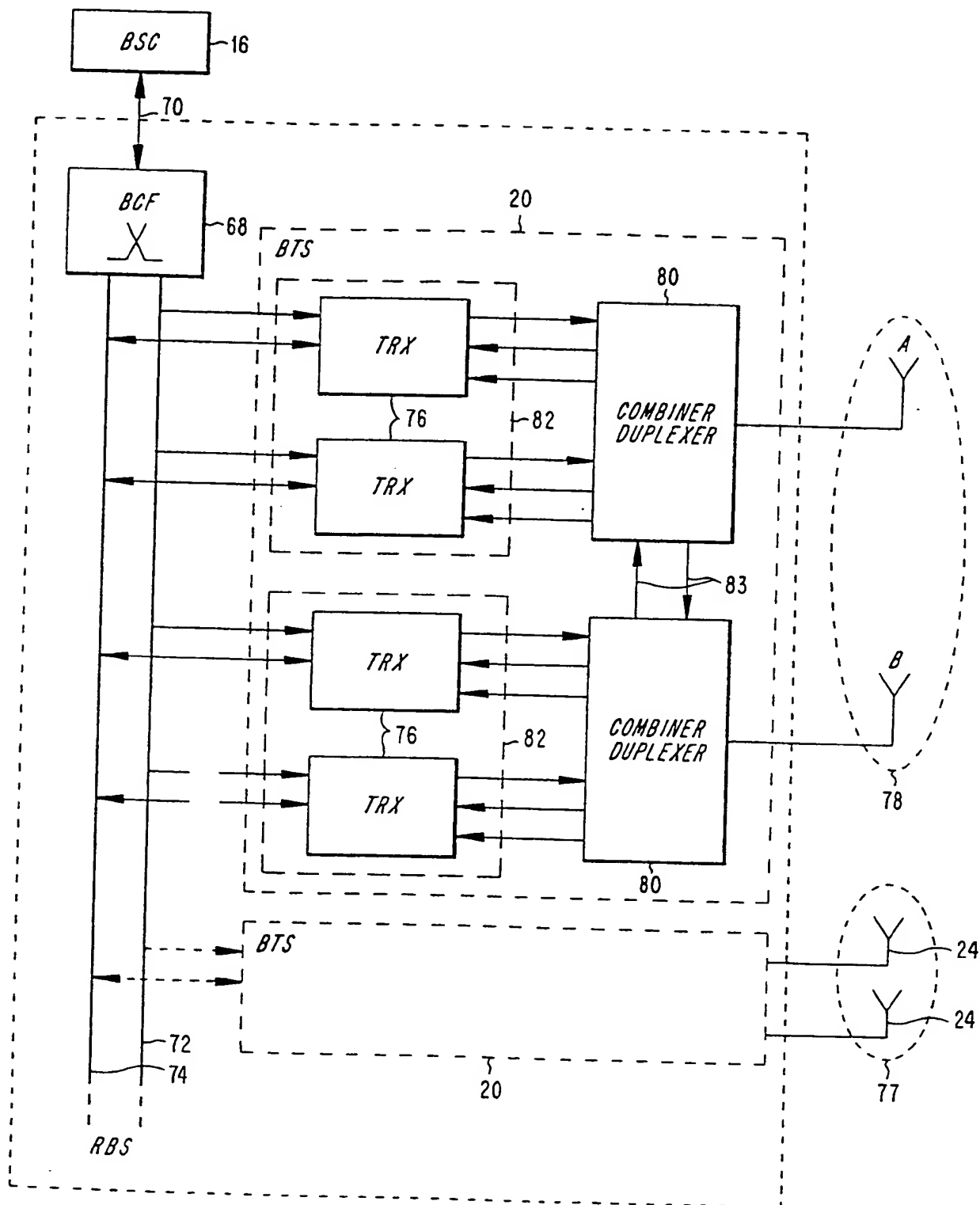


FIG. 5



6/10

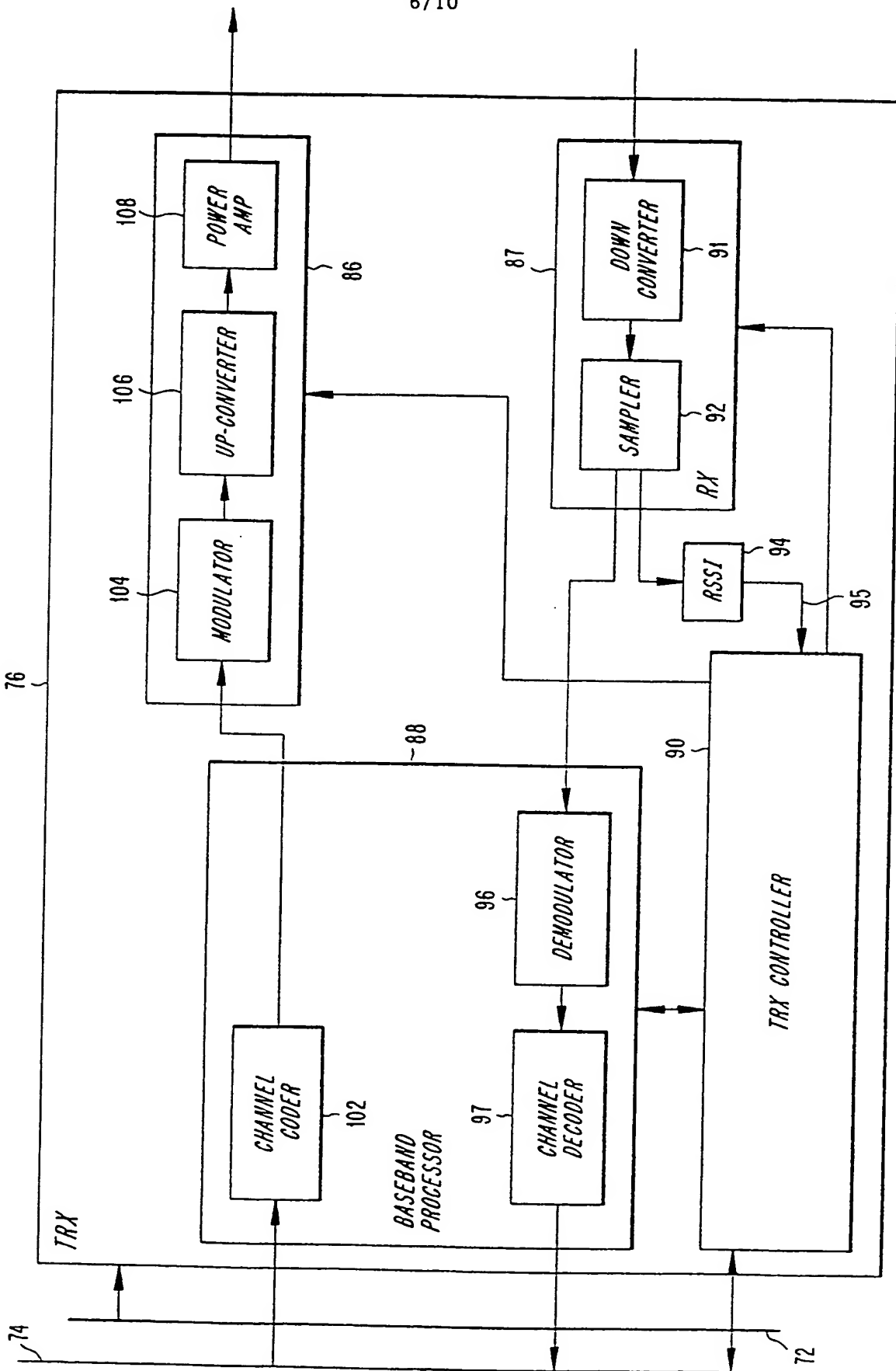


FIG. 7

7/10

FIG. 8

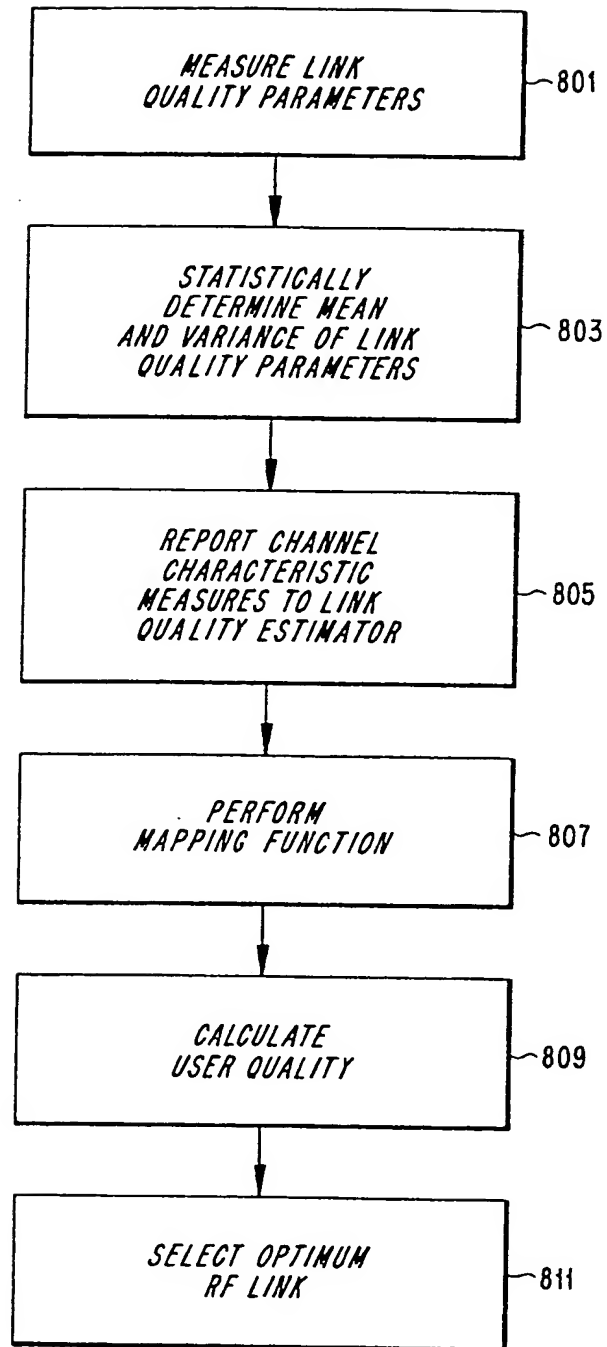
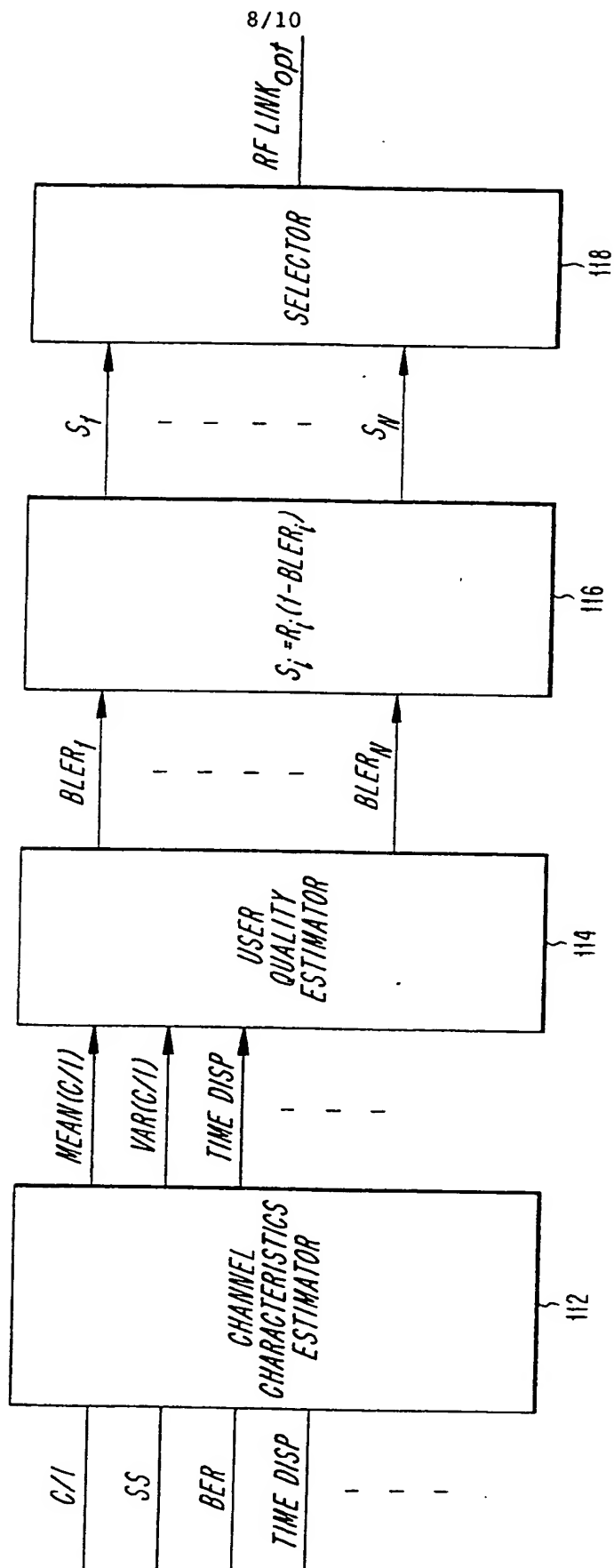


FIG. 9



9/10

FIG. 10

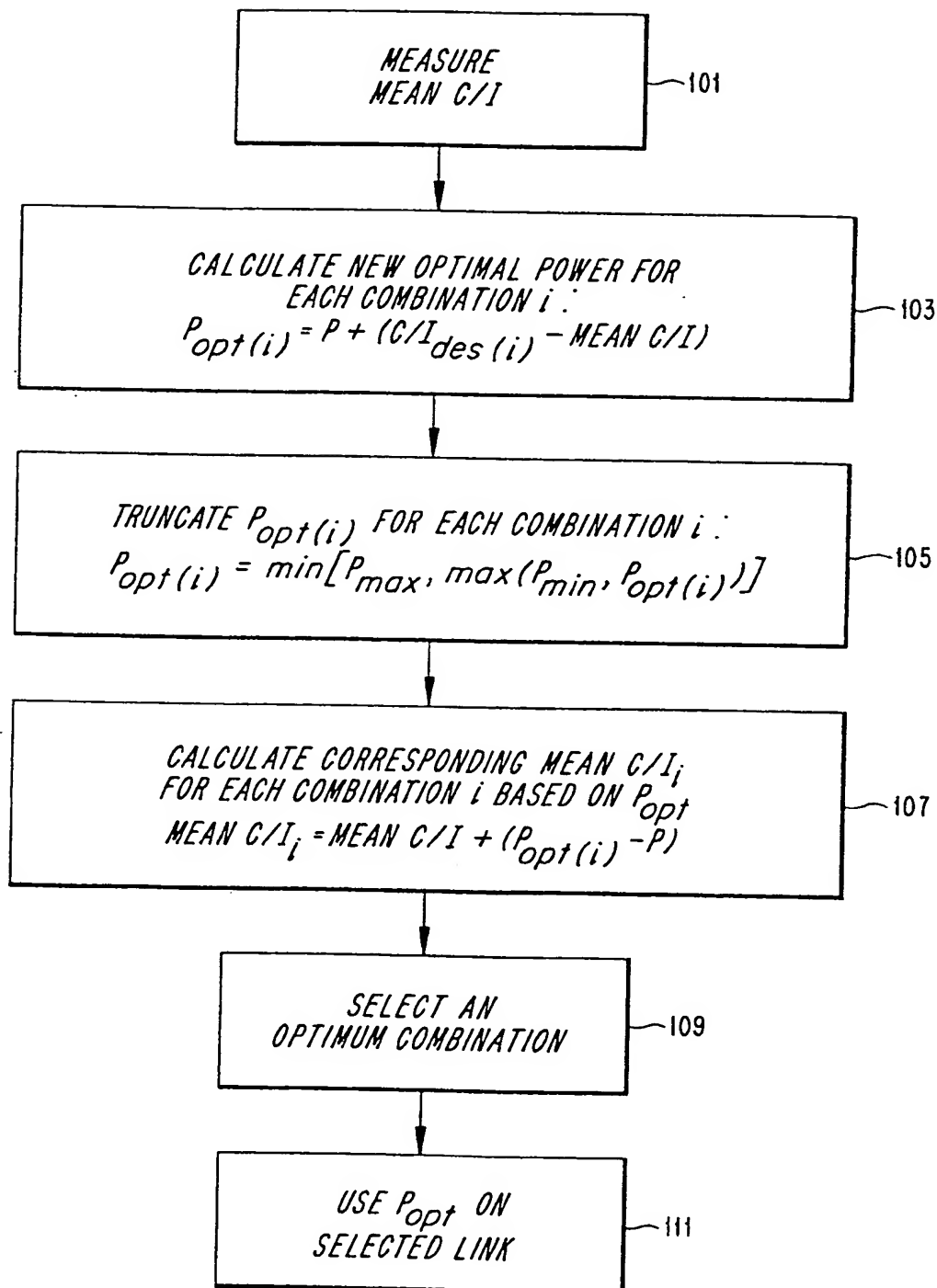
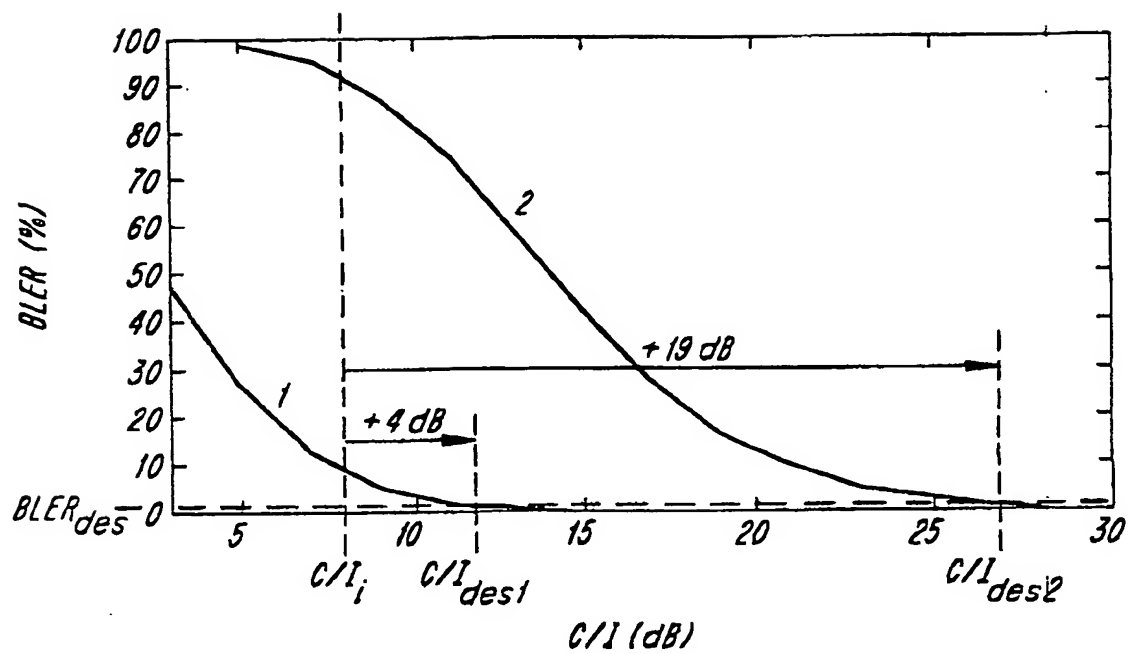


FIG. 11



INTERNATIONAL SEARCH REPORT

International Application No

PCT/SE 98/01538

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04L1/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KLEIDER J E ET AL: "An adaptive-rate digital communication system for speech" 1997 IEEE INTERNATIONAL CONFERENCE ON ACOUSTICS, SPEECH, AND SIGNAL PROCESSING (CAT. NO.97CB36052), MUNICH, GERMANY, vol. 3, 21 - 24 April 1997, pages 1695-1698, XP002063869 ISBN 0-8186-7919-0, 1997, LOS ALAMITOS, CA, USA, IEEE COMPUT. SOC. PRESS, USA see abstract	1,2,5-7, 11,12, 15,26, 27, 30-32, 34-37, 39-41
Y	* sections 2.E, 2.F, pages 1696-1697 *	3,4,8, 13, 16-23, 28,29, 33,38
	--- -/--	

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- "&" document member of the same patent family

Date of the actual completion of the international search

10 December 1998

Date of mailing of the international search report

17/12/1998

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Ghigliotti, L

INTERNATIONAL SEARCH REPORT

International Application No

PCT/SE 98/01538

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 97 13388 A (ERICSSON TELEFON AB L M) 10 April 1997	1,2,5-7, 11,12, 15,26, 27, 30-32, 36,37, 39-41
Y	see abstract see page 3, line 11 - line 14 see page 5, line 5 - line 23	3,4,8, 13, 16-23, 28,29, 33,38
Y	see page 12, line 24 - line 27 see page 13, line 1 - line 32 --- EP 0 731 573 A (PHILIPS ELECTRONIQUE LAB ;PHILIPS ELECTRONICS NV (NL)) 11 September 1996 see abstract see page 4, line 43 - line 56 ---	3,4,8, 16-23, 28,29,33
Y	EP 0 154 565 A (CODEX CORP) 11 September 1985 see page 2, line 1 - line 16 see page 13, line 26 - page 14, line 3 ---	3,4,8, 16-23, 28,29,33
Y	WO 93 00751 A (MICROCOM SYSTEMS INC) 7 January 1993 see abstract see page 7, line 8 - line 23 see page 12, line 22 - line 29 see page 15, line 2 - line 8 ---	13,38
A	see page 15, line 2 - line 8 ---	6,7,21, 22,31, 32,40
A	EP 0 137 695 A (FUJITSU LTD ;RICOH KK (JP)) 17 April 1985 see abstract see page 7, line 11 - line 18 see page 16, line 32 - page 18, line 11 see figure 6 -----	3,4,18, 19,28,29

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/SE 98/01538

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9713388 A	10-04-1997	US 5701294 A AU 7150696 A EP 0853863 A	23-12-1997 28-04-1997 22-07-1998
EP 0731573 A	11-09-1996	FR 2731571 A JP 8265228 A US 5802446 A	13-09-1996 11-10-1996 01-09-1998
EP 0154565 A	11-09-1985	US 4756007 A CA 1253229 A DE 3584176 A JP 1980563 C JP 6095666 B JP 61001130 A	05-07-1988 25-04-1989 31-10-1991 17-10-1995 24-11-1994 07-01-1986
WO 9300751 A	07-01-1993	US 5241565 A AU 2295292 A	31-08-1993 25-01-1993
EP 0137695 A	17-04-1985	JP 2012849 C JP 7022324 B JP 60051071 A CA 1225712 A US 4630126 A	02-02-1996 08-03-1995 22-03-1985 18-08-1987 16-12-1986

**This Page is Inserted by IFW Indexing and Scanning
Operations and is not part of the Official Record**

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☐ **BLACK BORDERS**
- ☐ **IMAGE CUT OFF AT TOP, BOTTOM OR SIDES**
- ☐ **FADED TEXT OR DRAWING**
- ☐ **BLURRED OR ILLEGIBLE TEXT OR DRAWING**
- ☐ **SKEWED/SLANTED IMAGES**
- ☐ **COLOR OR BLACK AND WHITE PHOTOGRAPHS**
- ☐ **GRAY SCALE DOCUMENTS**
- ☐ **LINES OR MARKS ON ORIGINAL DOCUMENT**
- ☐ **REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY**
- ☐ **OTHER:** _____

IMAGES ARE BEST AVAILABLE COPY.

As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.